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## ORIGINAL ARTICLES.

### On a Small Collection of Fossil Plants from the Tanganyika Territory.

By A. C. Seward, F.R.S., Pres.G.S.

WITH NOTES ON THE TANGA BEDS BY DR. E. O. TEALE.

PLATE XVII.

THE specimens submitted to me were obtained by Dr. E. O. Teale in the Tanga Hinterland in the Tanganyika Territory from beds assigned by Bornhardt to the Stormberg series of the Karroo system. Tanga is situated approximately on Lat. 5° S. Owing to the imperfect state of preservation and the fragmentary nature of the specimens, which occur as impressions on a hard laminated arenaceous shale, it is impossible to express with confidence an opinion on the precise geological horizon of the beds or to assign all the fossils to a definite position in the vegetable kingdom.

My opinion is that the plants indicate either a Triassic or a Rhætic horizon.

Dr. Teale has kindly contributed a map of the district and the following notes :—

"The beds in which the identifiable plant fossils were found form the middle or dark shale division of a sedimentary series which comprises a considerable portion of the coastal zone of the Tanga district. (See map, fig. 1.)

"The region was described in 1900 by Bornhardt,[1] who regarded the beds as representing the upper portion of the Karroo system ; he suggested their correlation with the Stormberg beds of South Africa. The present palæontological examination ponits to a greater affinity of the plants with European than with South African forms, and there is a strong probability that the Tanga rocks represent a distinct and later basin than those with typical Lower Karroo characters further south and south-west in the territory and elsewhere in South Africa.

"The area which these rocks embrace is included between the coast on the east and the margin of the crystalline rocks to the west at about 20 miles inland. The southern boundary of the exposures lies a little to the north of the Tanga-Moshi railway line, along which

[1] W. Bornhardt, *Zur Oberflächengestaltung und Geologie Deutsch-Ost-Afrikas*, Deutsch-Ost-Afrika, vii, 1900.

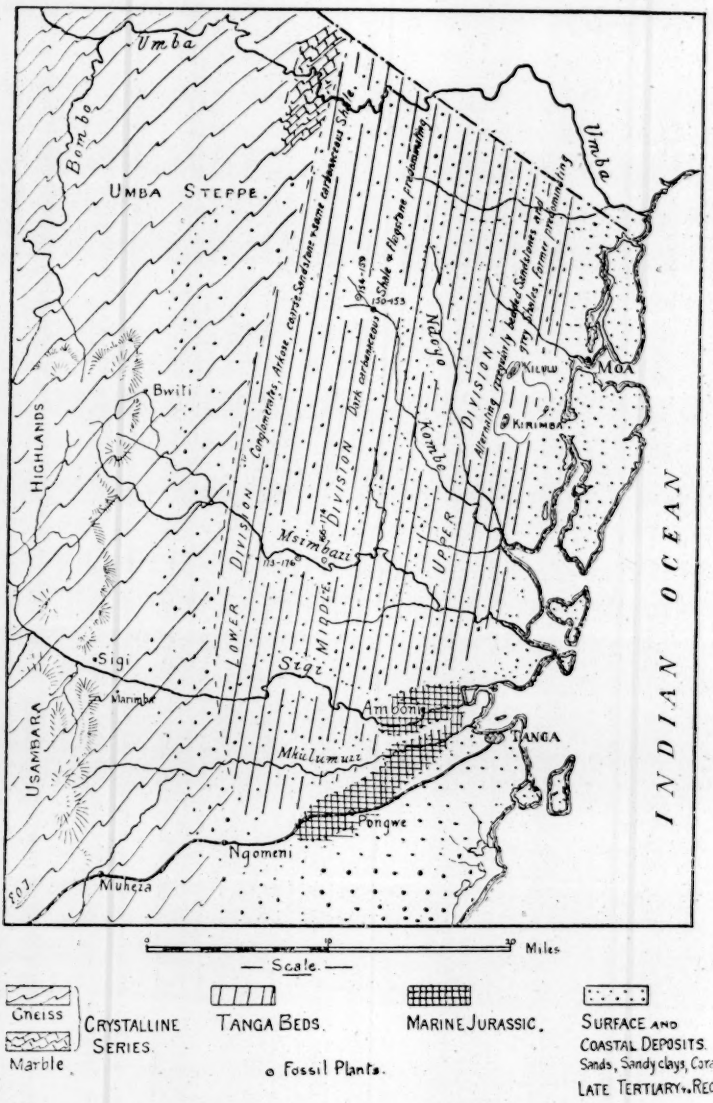



FIG. 1.—Geological Sketch-map of Tanga District, Tanganyika Territory.

the later marine Jurassic beds and young superficial sands and sandy clays mask the older sediments. In the north the beds pass into Kenya Colony, largely covered with a capping of sands.

"Good sections of the rocks are to be seen along the relatively deeply cut valleys of the Kombe, the Msimbazi and the Sigi. Much of the intervening country is covered with a thin capping of sands and

sandy clays, probably never exceeding 100 feet in thickness, and generally much less.

"In general this area may be described as a slightly uplifted peneplain with a gentle slope eastwards from about 800 feet above sea-level along its western margin to about 200–150 feet at a distance of two to five miles from the sea, where it drops fairly steeply to the relatively narrow coastal platform of coral rock and tidal mangrove swamps and estuaries.

"The sediments under consideration fall roughly into three divisions, a lower, middle, and upper group. In the lower division conglomerates, arkose and felspathic sandstones predominate, but numerous bands of dark carbonaceous shale are interbedded. These beds probably correspond with the Tarn Grits [1] of Kenya Colony. No identifiable fossils have been obtained from them in this territory, but comminuted plant remains are abundant in the interbedded dark shales.

"The middle division appears to follow conformably and is distinguished by a considerable thickness of strata in which dark carbonaceous shales and flagstones prevail. They contain abundant plant remains, unfortunately poorly preserved, but nevertheless yielding the best fossils of the region. These beds may correspond with the Maji-ya-Chumvi beds [2] of Kenya, though the shales have not yet provided any very satisfactory fossils comparable with those of Tanganyika territory.

"The upper division follows without any break and consists of irregularly bedded sandstones alternating with lighter coloured somewhat sandy shales. Sandstones tend to predominate in this section and show considerable range in texture and appearance. One characteristic type occurs near Vijinga, just above the junction of the Ndoyo and the Kombe: it is fine-grained and minutely false-bedded and weathers to a peculiar almost woody structure. Another type, that of Kirimba and Kilulu hills is very coarse grained and poorly cemented. The shales contain occasional though fragmentary plant remains. This group probably includes representatives of the remaining upper portion of the Duruma Sandstone of Kenya,[3] such as the Mariakani and Mazeras Sandstones and the Shimba Grit.

"The whole series has a uniform dip seawards at a low angle ranging from 5 to 10 degrees. Local small undulations occur but do not disturb the general structure and succession. A pronounced and persistent zone of minute puckering in certain of the shale bands of the middle division was traced at intervals along the strike throughout the region. The only evidence of faulting noted was along the

[1] H. B. Maufe, Report relating to the Geology of the East African Protectorate, Col. Rep., Misc. No. 45 (Cd. 3228), London.

[2] H. B. Maufe, op. cit.; and J. W. Gregory, *The Rift Valleys and Geology of East Africa*, 1921, p. 52.

[3] H. B. Maufe, op. cit.

western base of Kilulu and Kirimba hills. The direction of the fault is about N.N.E., that is parallel with the coast, and the sandstone here dips at a high angle to the east in contrast to the prevailing dip elsewhere.

"A moderate estimate indicates a thickness of at least 10,000 feet of sediments in this region."

### Description of the Specimens.

Two of the specimens, though not in my opinion of vegetable origin, are sufficiently interesting to be briefly described.

A slightly raised portion of the rock, approximately circular in outline and differing from the rest of the matrix, shows a smooth border and, in the central region, a very indistinct division into a few cuneate radially disposed areas. In one specimen the circular body is 9 cm. in diameter; it is bounded by a well-marked line or low ridge, which forms the edge of a very slightly depressed smooth border, rather less than 1 cm. broad. This smooth border surrounds a central area, exhibiting vaguely a radial disposition of segments similar to those in the smaller specimen.

Except in their smaller size, the specimens resemble a supposed fossil alga described by Walcott,[1] from Algonkian rocks in Montana as *Gallatinia pertexa*, which, I venture to think, is a fractured septarian nodule. Comparison may be made also with impressions of Medusæ, e.g. *Rhizostomites admiranda* Haeck,[2] from the lithographic slate. While favouring an inorganic origin, I suggest that the specimens are worthy of examination by a palæozoologist.

### Planta incertæ sedis. ? Eretmophyllum sp. Plate XVII, Fig. 1.

This specimen shows the impression of what appears to be a thick leaf with a linear sessile lamina 7 cm. long, not quite complete at the distal end: the apex was probably obtuse; it is longitudinally striated and in addition to the striæ, the expression probably of some fibrous tissue, there are a few prominent longitudinal ridges about 1 mm. apart, which diverge and fork from the base, and probably mark the position of veins. It is difficult to assign this specimen to a precise systematic position; while superficially resembling some leaves of *Schizoneura* figured by Feistmantel[3] from Gondwana beds in India, the agreement is by no means sufficiently close to justify inclusion in that genus. It resembles also detached leaves figured by the same author from Jurassic (Upper Gondwana) rocks in India,[4] and referred on insufficient evidence to the Jurassic European species *Podozamites lanceolatus* Lind. and Hutt. The Tanga specimen is, I am convinced, not a leaf of *Podozamites*. It

[1] C. D. Walcott, "The Precambrian Algonkian Algal Flora": *Smithsonian Miscell. Coll.*, vol. lxiv, No. 2, 1914, pl. xxiii.

[2] K. A. von Zittel, *Grundzüge der Paleontologie*, 1895, p. 111, fig. 216.

[3] Feistmantel, Foss. Flor. Gondwana system, vol. iii, pt. ii, 1880, pls. ia, etc.

[4] Ibid., vol. iv, pt. i, 1882, pl. ii, fig. 6.

may, however, be closely allied to some leaves of similar form described by Mr. Hamshaw Thomas [1] from Jurassic rocks of Yorkshire, and assigned by him to a new genus, *Eretmophyllym*. A species of the same genus has also been recorded from Jurassic beds in Afghanistan. In habit and in venation the African specimen agrees with *Eretmophyllum*, but in the absence of further information, such as could be afforded by the characters of the cuticle were the preservation better, precise identification is hardly possible.

Ullmannia sp. Figs. 2–5.

Some of the specimens represent shoots bearing overlapping, spirally disposed, linear-ovate leaves, reaching a length of about 1 cm., and 3 mm. in breadth. On some detached leaves there is a faint indication of an oval scar (Figs. 4, 5) at the base, where the lamina was attached to the stem. The venation is not preserved. The leaf impressions often show traces of ridges (Fig. 4), suggesting that the lamina was comparatively thick and possibly quadrangular in section.

Other specimens, though of the same general type, show a more compact habit; the leaves are rather shorter and more appressed to the axis. All the shoots referred to *Ullmannia* closely resemble in habit *Ullmannia frumentaria* (Schl.) and *U. selaginoides* (Brongn.), which are common plants in the Zechstein copper slate of Thuringia.[2] It is difficult to draw any satisfactory line between vegetative shoots included by authors in the two genera *Ullmannia* and *Voltzia*, and our knowledge of the affinities of fossils referred to them is comparatively meagre.

? Ullmannia sp. Figs. 6, 7.

Two of the specimens are characterized by shorter leaves, 4 mm. long, inclined at a wider angle to the axis; they resemble the European species *Ullmannia Bronni* Goepp., and may be compared also with fossils from Thuringia figured by Geinitz and others as *Voltzia Liebeana* Gein. It should, however, be pointed out that pieces of vegetative shoots such as these may be generically identical with Jurassic species included in the comprehensive genus *Pagiophyllum*.

Voltzia sp. Figs. 8, 9.

Lobed, fan-shaped scales, from 5 to 8 mm. broad at the distal margin, which are in all probability scales from strobili of a species of *Voltzia*. They are apparently sterile, though seeds may have been originally attached to them as in similar scales recorded from Thuringia. The specimens are of the same type as those figured by Potonié [3] from the Tanganyika territory in association with,

[1] H. H. Thomas, *Proc. Cambridge Phil. Soc.*, vol. xvii, pt. iii, 1913.

[2] H. B. Geinitz, "Nachträge zur Dyas I.": *Mitt. K. Mineralog. Geol. und Prachist. Mus. Dresden*, Heft 111. 1880.

[3] H. Potonié, *Fossile Pflanzen aus Deutsch- und Portugiesisch-Ost-Afrika*, 1900.

vegetative shoots resembling some of those collected by Dr. Teale. Potonié instituted a new generic name *Voltziopsis* for the fragments submitted to him, but in a recent edition of his textbook, edited by Dr. Gothan,[1] he wisely abandoned a designation which was unnecessary and simply described the fossils as agreeing generally with Jurassic species named by Heer *Leptostrobus*. There is, however, no proof that the African specimens conform to the characters of Heer's genus. Scales similar to the Tanganyika impressions have been described by Nathorst from Rhætic strata in Scania as *Swedenborgia cryptomerides*.[2] It is with scales usually included in *Voltzia* that the specimens agree most closely, at least in form, though they are smaller than most of the European examples from Bunter and Zechstein beds.

## Conclusion.

The fossil plants described by the late Dr. Potonié from the Tanganyika territory in 1900 [3] consist of small pieces of vegetative shoots and lobed scales generically identical with Dr. Teale's specimens referred to *Ullmannia* and *Voltzia*. The more recently acquired material includes coniferous branches which exhibit a greater range in habit than those figured by Potonié, and the scales are rather smaller than those he recorded; the differences are unimportant. The single leaf (specimen 175) and the specimens which I am inclined to regard as inorganic are unrepresented in the German collection. The evidence furnished by the *Ullmannia*-like fragments and the *Voltzia* scales would seem to favour comparison of the plant beds with Permian and Triassic strata in Europe. It is probable that both shoots and scales belong to the same genus; but though it may seem illogical to employ distinct generic names for fossils which may be parts of the same plant, I adopt the designations *Ullmannia* and *Voltzia* on the ground that they best describe the features of the two kinds of specimens.

Coniferous branches agreeing closely in habit with some of those from the Tanga Hinterland occur also in Rhætic and Jurassic rocks, but the association of the *Voltzia*-like scales is a point in favour of a somewhat lower horizon. The leaf compared with *Eretmophyllum*, though too imperfect to be identified with precision, accords more with a Rhætic or Jurassic age.

It is noteworthy that the Tanga collection does not include any examples of the genus *Glossopteris*, and while it is often unsafe to attach much importance to negative evidence, especially when the data are few, the presumption is that the flora is distinct in facies from Upper Palæozoic and Lower Mesozoic floras obtained from other parts of Africa. The Tanga flora is rather European than African in type. *Glossopteris* is recorded from several regions in the

[1] H. Potonié, *Lehrbuch der Palaeobotanik*, 2nd ed., 1921, p. 322.
[2] A. C. Seward, *Fossil Plants*, vol. iv, 1919, pp. 296 *et seq.*
[3] H. Potonié, *loc. cit.*

Tanganyika territory: from near Kissakki,[1] about 180 miles south of the Tanga Hinterland; from the Uchunga Mountains,[2] rather more than 100 miles south-west of Kissakki; from Ituli,[3] 500 miles south of Tanga, and from the southern extremity of Lake Nyasa,[4] slightly over 400 miles south-west of Ituli.

The description by Zeiller in 1883 of certain European species of Upper Carboniferous plants from the Tete basin (Zambesi) seemed to prove the existence during the period of the Coal Measures of a northern flora in close association with the southern or *Glossopteris* flora, and it was assumed that *Glossopteris* and its associates were absent from the Zambesi basin. A few years ago Dr. Potonié showed that the plants described by Zeiller could not have been collected *in situ*, but were of European origin; he also demonstrated the occurrence of *Glossopteris*, and so proved the extension of the *Glossopteris* flora into the region of the Tete basin.

The genus *Voltzia* was recorded by Feistmantel[5] from Lower Gondwana rocks in India in 1881; the vegetative shoots assigned by him to the European Bunter species *Voltzia heterophylla* Brongn. may or may not be correctly determined. A recent examination of a lobed scale of the *Voltzia* type, figured by Feistmantel, led me to regard it as affording evidence in favour of Feistmantel's determination.[6] As already stated, authors have not been consistent in the use of the generic names *Ullmannia* and *Voltzia*, and, indeed, no clear distinction can be drawn in the absence of reproductive organs. Specimens of vegetative shoots of the *Ullmannia* or *Voltzia* habit occur in the Permian of Europe as well as in the three series of the Triassic system.[7] Shoots of this general type are on the whole more characteristic of northern than of southern floras.

Taking into account the whole of the palæobotanical evidence, my opinion is that while some of the specimens agree more closely with European Zechstein forms than with any later species, the balance of evidence points to a higher horizon, whether Triassic or Rhætic cannot be definitely determined. If it is assumed that the absence of *Glossopteris* means its non-existence in the Tanga flora, this would furnish an argument in favour of a geological position at least as high as Uppermost Triassic or Rhætic. *Glossopteris* lingered on into the Upper Triassic period in Natal and Indo-China,[8] and while

[1] H. Potonié, *loc. cit.*

[2] W. V. Brehmer, *Bot. Jahrb.* (*A. Engler*), Bd. li, Heft 3 and 4, 1914, p. 399.

[3] E. A. N. Arber, *Quart. Journ. Geol. Soc.*, vol. lxvi, 1910, p. 237.

[4] H. Potonié, *Palaeobotanische Zeitsch.*, Bd. i, Heft i, 1912, p. 36. See also Potonié, "Die fossile Flora des Tete-Beckens am Sambesi": reprint from the *Branca Festschrift*, 1914 (Berlin).

[5] O. Feistmantel, *Foss. Flor. Gondwana System*, vol. iii, pt. iii, 1881.

[6] A. C. Seward and B. Sahni, "Indian Gondwana Plants: a Revision": *Mem. Geol. Surv. India*, vol. vii, 1920, p. 1.

[7] E. Schütze, "Beiträge zur Kenntniss der Triassischen Koniferen-Gattungen *Pagiophyllum*, *Voltzia* und *Widdringtonites*": *Jahresheft Ver. Vaterl. Naturkunde in Württemberg*, 1901, p. 256.

[8] A. L. du Toit, *South African Journ. Sci.*, vol. xviii, 1921, p. 120.

we cannot be certain that it did not grow in association with the Tanga plants, its absence may well be significant. It must be admitted that some of the coniferous shoots from Tanga bear a close resemblance to fossils from Jurassic rocks, but the scales which I have referred to *Voltzia* appear to be nearly allied to Lower Triassic forms. Moreover, the specimens with the longer type of leaf included in *Ullmannia* agree most closely with Upper Permian and Triassic species.

A few imperfectly preserved plant fragments are recorded by Mercenier [1] from localities in the Belgian Congo, a few miles west of Lake Tanganyika. So far as it is possible to base an opinion on the sketchy published drawings, the fossils would seem to support Mercenier's view that the rocks may correspond in age to the Ecca series of South Africa. No examples of *Glossopteris* are mentioned; a piece of a *Noeggerathiopsis*-like leaf is figured and portions of some Lepidodendroid stems. The specimen referred by Mercenier to *Stenopteris elongata* Carr, is not determinable.

EXPLANATION OF PLATE XVII.

FIG.
1.—? *Eretmophyllum* sp. Nat. size.
2.—*Ullmannia* sp. Nat. size.
3.—*Ullmannia* sp. 1¼ nat. size.
4, 5.—Detached leaves of *Ullmannia*. 2⅕ nat. size.
6.—*Ullmannia* sp. 1⅘ nat. size.
7.—? *Ullmannia* sp. Nat. size.
8, 9.—*Voltzia* sp. Twice nat. size.

## The Karstlands of Western Yugoslavia.

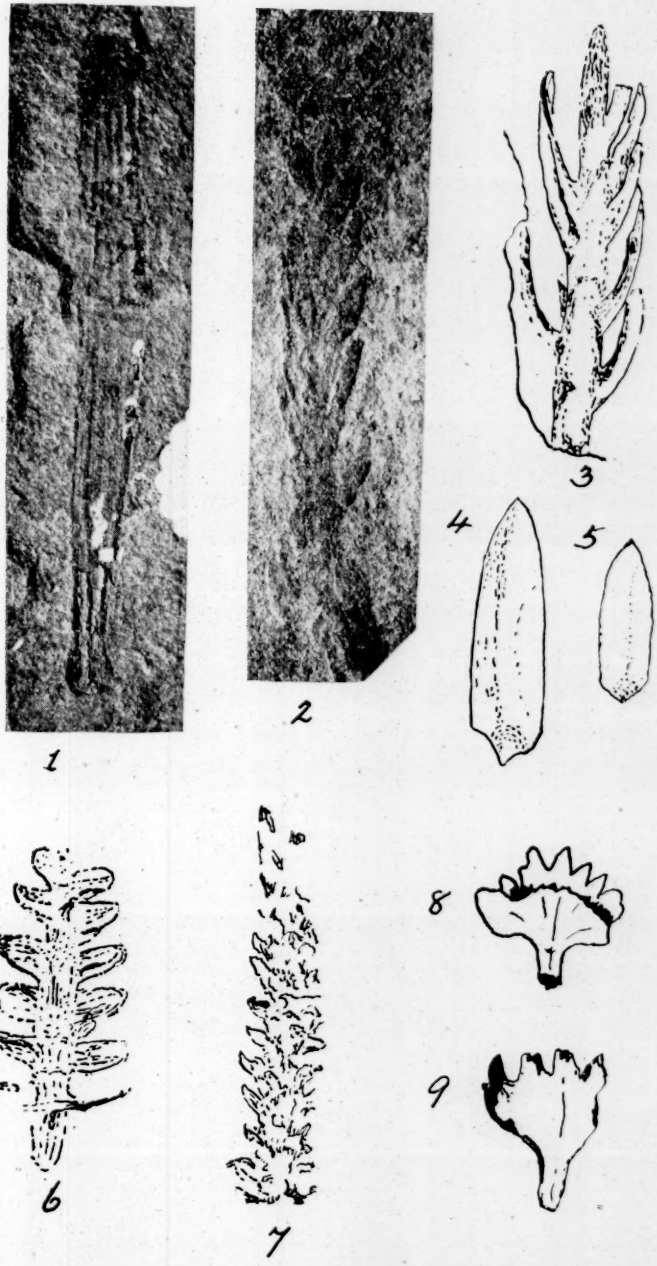
By D. A. Wray, M.Sc., F.G.S.

### Introductory.

Western Yugoslavia, which broadly corresponds to the ancient Roman province of Illyricum, includes Dalmatia, Herzegovina, and Montenegro, together with the western portions of Slovenia, Croatia, and Bosnia. It is a region of high geological interest, for within it and the adjoining portions of Italy the "Carso" or "Karst" lands are developed on a scale perhaps unequalled elsewhere. Considerable attention has been devoted from time to time to their leading features by Austrian, Italian, and Serbian geologists, though the study of these land forms has hitherto received but little attention in England. No excuse therefore seems necessary for drawing attention to some of the more salient features of this interesting district.

Karstland is a term which has been applied by physiographers to a barren and stony limestone district, largely devoid of surface waters. As little sediment results from the denudation of limestone

[1] Mercenier, Ann. Soc. géol. Belg. Publications relatives au Congo Belge, etc. Ann. 1912–13, Annexe au Tome xl, 1913.




? *Eretmophyllum* (1); *Ullmannia* (3–7); *Voltzia* (8, 9).

[*To face p. 392.*

districts, there is practically no soil-covering in such regions, while such as is formed is rapidly carried away by the wind or occasional rainfall, with the result that the limestone surface is irregularly fretted, and cut up by innumerable clefts or hollows known throughout the Western Balkans as *grićs* (cf. English *grikes*); while its lower portions are honeycombed with caverns and an intricate subterranean drainage system. The very uncertain water-supply

FIG. 1.—Orographical sketch-map of Western Yugoslavia, illustrating the occurrence of poljes and other depressions following the Dinaric trend.

and scanty soil-covering of such regions have a preponderating effect on the distribution of the population; and the majority of the settlements are clustered together on the floors of the scattered inland drainage basins, while the thin veneer of red earth (or terra-rossa) which floors such areas is carefully enclosed by loose stone walls and terraces.

KARST PHENOMENA IN OTHER DISTRICTS.

In Britain such features find perhaps their closest parallel in the Craven district of Yorkshire, where the floor of the Carboniferous Limestone to the north of Settle is cut up by irregular widened joints known as "grikes", the fretted limestone surface being locally described as "clints". "Kelds" or springs where streams emerge from an underground course are a distinctive feature of the landscape; while the numerous vertical chasms locally known as "gills" or "pots" form an exact counterpart to the Illyrian ponors. The intricate underground drainage of this region has been closely studied by the Yorkshire Geological Society,[1] whose general results appear to be in close accord with those obtaining on the more extensive Illyrian karstlands. On the Continent similar features have been observed in the Devonian limestones around Rochefort and Han-sur-Lesse in Belgium, though it is in the south of France where the karst attains its greatest development in Western Europe. Here, to the north-west of Montpellier, in the wind-swept uplands known as the Causses, very pure and thick Jurassic limestones have a wide development. The only fertile and habitable regions on these barren plateaus are the "sotches" or hollows, where the red earth formed by the denudation of the limestone is preserved in large funnel-shaped hollows, which correspond in every way to the dolinas of Western Yugoslavia. The physiography of the Causses has been exhaustively studied and described by the eminent French speleologist, Martel (4).[2]

Karst phenomena are not infrequent in the Alpine limestone districts; here the irregular limestone surfaces are termed *lapiés*, while the weathering process is described as *lapiésation*. In Switzerland, notably in the canton Glarus, these bare surfaces known as *Karrenfelder* have been the subject of detailed studies by Heim (1). Karst features are also specially notable at high altitudes in the Jura mountains, where the deep, irregular grooves and trenches which intersect the bare limestone pavements are called *lézinnes*.

Many limestone districts in the Iberian peninsula form typical karst landscapes; they are especially noticeable in Andalusia, and also on the Mesozoic limestone plateau to the north of the river Tagus in Portugal; the latter area has been described in much detail by Fleury (12), who records the occurrence of all the distinctive features of a typical karstland. Karst phenomena are also admirably displayed in many places in the Central and Southern Apennines, notably in the Abruzzi; while in the Southern Balkans the barren limestone wastes of the Peloponnesus exhibit similar features.

Finally, on the American continent, these features appear to have a very widespread development on the limestone areas in the basin

[1] *Proc. Yorks. Geol. Soc.*, vol. xv, 1905, p. 248.

[2] Numbers in brackets refer to the Bibliography given at the end.

of the Ohio in Kentucky and Southern Indiana, where the labyrinthine Mammoth Cave, containing a system of lakes and streams at varying levels, constitutes the most remarkable instance of underground drainage that has yet been discovered.

## Extent of the Illyrian Karstlands.

The actual limits of the Illyrian karstlands can be drawn with considerable precision. From the eastern end of the plains of Lombardy, they extend as a broad band through most of Western Slovenia, and from the coast at Trieste they reach nearly as far inland as Ljubljana (or Laibach). The Julian Alps limit the true karst to the north, the valleys of the Idria and the Sora forming a fairly precise boundary between two distinctive types of landscape. In Western Croatia the karst extends from the coast to the edge of the Save plain, while it also includes practically the whole of Istria, Dalmatia, Herzegovina, and much of Western Bosnia. In Montenegro two diverse types of land forms are met with. Thus the country to the west of the Zeta valley constitutes a barren karstland, while to the east in the region known as the Brda a typical upland landscape occurs, thickly wooded and with perennial streams of considerable volume.

The southern limit of the Illyrian karstlands is formed by the Northern Albanian Alps, which consist in the main of massive Cretaceous dolomites, and rise abruptly to over 10,000 feet above sea-level. To the Southern Slavs they are appropriately known as the Prokletije Planina (or Accursed Mountains), a very apt reference to their barren karst-like nature.

## Geological Structure.

The karstlands consist predominantly of Triassic, Cretaceous, and older Tertiary limestones. The oldest rocks met with in the area are the Upper Carboniferous limestones, sandstones, and breccias, which form small inliers around Delnice (or Petrova Gora) in the Kapela Mountains, and also around Budua and Castel Lastua to the immediate south of the Gulf of Cattaro. Broadly speaking, the karst may be subdivided geologically into two main parallel belts; a coastal strip in which Cretaceous and Tertiary limestones predominate, while to the east of a line drawn from Tolmino in the upper Isonzo valley, through Adelsberg, along the foot of the Velebit range and continued southwards past Knin and Mostar to the base of the Durmitor range in Montenegro, the massive Triassic limestones underlie most of the region. These Triassic rocks consist principally of fossiliferous limestones and dolomites belonging to the "open sea" Alpine type, while the Cretaceous formation includes massive dolomites, and limestones characterized by the abundance of *Hippurites* and *Rudistes*. The considerable alteration these beds have undergone renders their precise correlation with other areas a matter of considerable difficulty.

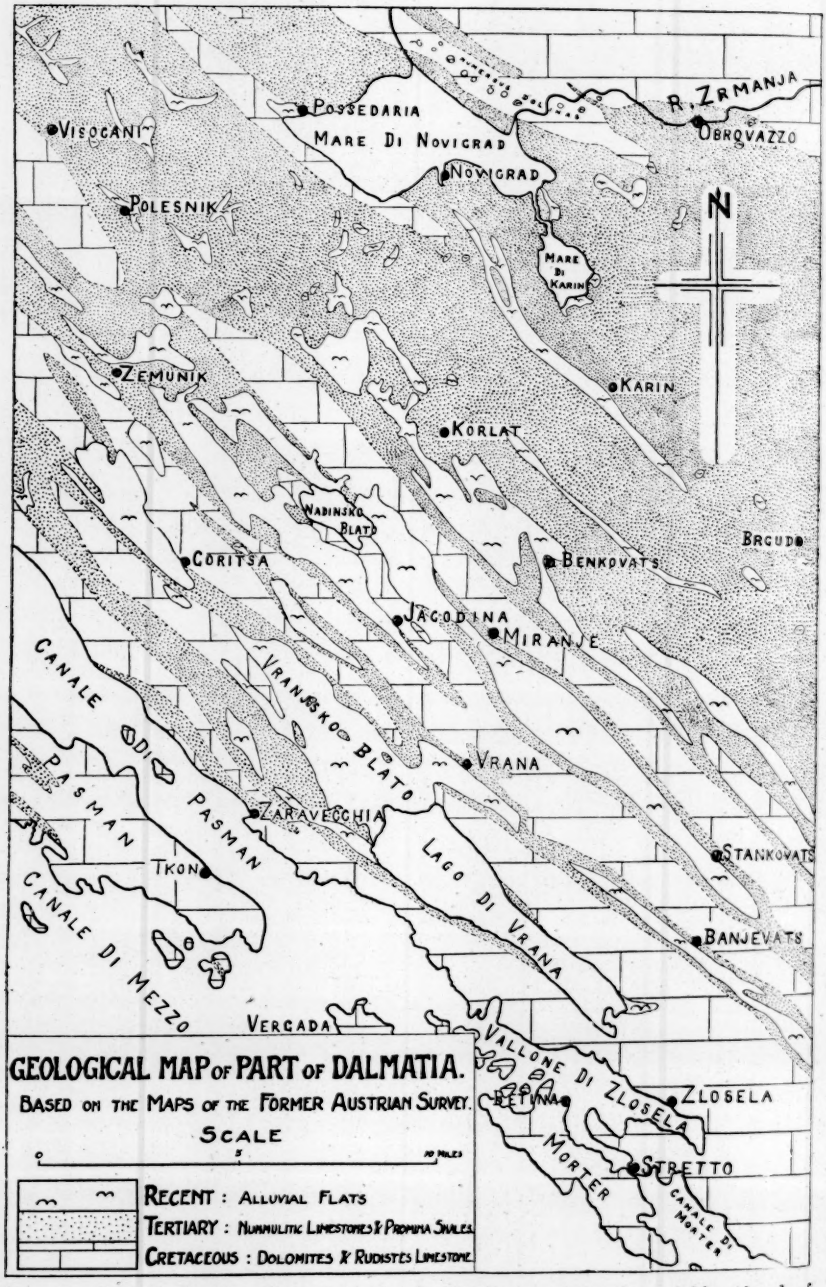



FIG. 2.—Geological map of part of the Dalmatian coast in the neighbourhood of Obrovazzo and Zaravecchia, illustrating the predominating effect of geological structure on the development of the drainage.

It is the above-mentioned Triassic and Cretaceous dolomites and limestones, remarkable for their extreme purity, that constitute by far the greater portion of the terrain on which the karst features are so admirably developed.

The base of the Tertiary formation in this region is indicated by freshwater limestones and marls, characterized by the shell *Cosinia*. Above these succeeds a series of Nummulitic and Foraminiferal limestones and marls; replaced, however, in Central Dalmatia by an extensive development of "Flysch", a thick arenaceous formation. The Promina Shale Series, which constitute the uppermost Eocene in Dalmatia, forms also essentially a sandy facies with thin alternations of marine limestones and marls. Marine limestones of Neogene age are only met with in Southern Montenegro; throughout the Illyrian karstlands the lacustrine Levantine deposits rest discordantly on the older Secondary and Lower Tertiary formations.

According to Penck, Schubert (11), and the former Austrian Geological Survey, the folding of the beds in this region took place in early Miocene times; since which period also this district has formed part of a land area. The rocks have been strongly folded and faulted by a series of overthrusts from the north-east and east, and the Eocene limestones which have participated in the movements form long strips trending south-east overridden in many places by Cretaceous limestones. Further inland, where the movement appears to have been more intense, masses of Triassic limestone have been thrust over Jurassic limestones, as in the notable case of the Idria quicksilver mines (where the complicated structure has been unravelled by Kossmatt),[1] and also around Sarajevo, Vares, and other localities in Central Bosnia. Many areas also formerly regarded as having a simple, basin-like structure in Northern Dalmatia have been shown by Schubert within recent years to have been strongly folded and inverted in many places, while in the Siverich coalfield, to the north of Sebenico, there is abundant evidence of powerful earth-movements both in the presence of overthrusting and the occurrence of shatter-belts (*Verrussungszonen*), along which the coals show an impure and earthy character.

The main axes of folding of the rocks in Western Yugoslavia follow a N.W.–S.E. (Dinaric) trend, but to this broad generalization there are several notable exceptions. Thus, in the neighbourhood of Sebenico the Dinaric N.W.–S.E. direction changes eventually to east and west. This strike is maintained in the islands of Brazza, Lesina, and Curzola, and also on the adjoining mainland around Spljet. In Southern Montenegro the Dinaric N.W.–S.E. system again curves inland, following the eastern and eventually E.N.E. trend of the Prokletije mountains or Northern Albanian Alps.

[1] F. Kossmatt, "Ueber die geol. Verhältnisse des Bergbaugebietes von Idria": *Jahrb. k. k. geol. Reichsanstalt*, Vienna, vol. xlix, 1899, pp. 262–81.

According to Cvijic[1] this range marks the southern limit of the Dinaric folded system, for the Albanian (or Pindaric) system, distinguished by its great development of "Flysch" with intrusive serpentines and other basic igneous rocks peculiar to the Albanian system, follows a north and south direction, eventually trending south-east and east in Southern Greece and Crete.

The area adjoining the Albanian gulf, corresponding broadly with the Lower Drin valley, and which occurs between the Dinaric and Albanian folded systems, has been shown to have been an area of intense earth-movement; and the former Austrian Survey[2] record that from Spizza to beyond Budua the Dinaric range is cut up by powerful thrusts into flakes which include the whole of the stratified series from the Lower Trias to the Lower Tertiary inclusive, thrust over one another in a south-westerly direction. The southern wall of the North Albanian Alps appears to be a line of fracture,[3] the limestone wall (at the base of which occur thermal springs at Drsnik and Banja) forming an abrupt northern face to the Drin marshes. The prominent Scutari and Cattaro depressions occur in this region of intense earth-movement, and here tectonic agencies have been supreme in determining their outlines. The original folds have been cut across by powerful fractures, so that in this district the geological and orographic lines rarely correspond.

Broadly speaking, the Western Balkans consist of a system of broad arcs, with their concave sides facing eastwards. This arrangement is well exemplified in the numerous Dalmatian islands and straits which run parallel with the coast like a festoon. The effect of these folds and their accompanying parallel fractures on the physiography of the karstlands is everywhere strongly marked.

## The Origin of the Present Drainage System.

It has already been pointed out that the main period of folding and uplift of this region took place in early Miocene times; consequently the present drainage system originated in the late Miocene or early Pliocene. The broad uplift along a main axial line parallel to and close by the Dalmatian coast resulted in the drainage being mainly diverted to the east into the Save and Danube basins. Thus along the whole Illyrian coast there are practically no rivers of any importance with the notable exception of the Narenta. The smaller streams, the Zrmanja, Cikola, and Cetina, follow closely the strike of the rocks; and in marked contrast to the rivers of Albania (which have large deltaic flats in their lower reaches), they enter the sea at one end of long fjord-like deep-water channels, avoiding the broad arms of the sea as estuaries.

[1] J. Cvijic, "Die dinarisch-albanische Scharung": *Sitzungsber. Akad. Wissensch.*, Vienna, vol. cx, 1901, p. 31.

[2] G. Von Bukowski, in *Verh. k. k. geol. Reichsanstalt*, Vienna, 1896, pp. 95–191.

[3] J. Cvijic, op. cit., pp. 37 et seqq.

With the continued uplift of this region, the main streams endeavoured to keep pace by cutting for themselves deep gorges in the limestones. Thus the river Una, after following the strike of the Triassic limestones as far north as Bihats, abruptly swings east, cutting steep-sided gorges in the Cretaceous, Jurassic, and Triassic limestones, before eventually draining into the Save. Similarly, the river Narenta in its course from the Jablonitsa mountains to the Mostar plain cuts through a series of impressive defiles, mainly in Triassic dolomites, whose abrupt slopes in places attain a height of over 2,000 feet above the level of the valley; while the river Zrmanja, in cutting its way across the strike of the Mesozoic limestones around Obrovazzo, forms a vertical-walled canyon, over 600 feet deep.

The majority of the streams seem, however, to have been unable to keep pace with the continued uplift, and consequently the whole of the Illyrian karstlands are studded with a series of inland drainage basins aligned in the direction of the Dinaric folds. The predominating effect of this structure on the development of the drainage is admirably illustrated along the Dalmatian littoral in the neighbourhood of Zaravecchia (see Fig. 2), where the Cretaceous and Tertiary limestones show the Dinaric trend, and the close correspondence between the synclinal hollows and the alluvial flats is very remarkable. While many of these closed basins occur between two minor anticlinal axes, the outlines of others have been determined in the main by longitudinal fractures. The latter type is a very distinctive land form throughout Western Yugoslavia, where it is universally termed a *polje*.

Probably the largest enclosed basin is that of Gospits, in Western Croatia, situate between the Velebit and Kapela ranges, where no less than seven streams of considerable size (severally known as the Lika) drain towards the centre of the basin, and for many months of the year convert much of it into a seasonal lake or marsh. Much of this inland basin is floored with Lower Pliocene freshwater limestones and marls with thick beds of lignite.

### Underground Drainage Systems.

Another consequence of the later Tertiary uplift has been that erosive action in the soluble limestones and dolomites has tended to work in a vertical direction, and many streams following the major joints in the limestone have cut intricate subterranean channels along their course. Thus the river Ljubljanitsa of Western Slovenia, where it rises near St. Peter, 50 miles west of Ljubljana, is first known as the river Poik. After flowing at the surface for some distance over Lower Tertiary limestones, breccias, and shales, it subsequently passes underground through the famous Adelsberg caves, and eventually reappears at the surface as the river Unz at Planina, where its volume is considerably augmented by the underground drainage of the Zirknitz inland depression. The Adelsberg

caves are cut in the massive Upper Cretaceous limestones, and the river Poik flows underground, where it passes from the more arenaceous Lower Tertiary rocks on to the highly jointed and massive Cretaceous dolomites and limestones. Where it emerges at Planina as the Unz it is brought to the surface by the discordant junction of these limestones with the underlying Triassic rocks. The river Unz, after a very brief career at the surface, is again lost to view to the south of Longatico (Loitsch) and ultimately reappears at the surface at Verhnika (Oberlaibach), where it assumes its final name.

The river Reka, in the hinterland of Trieste, furnishes another striking instance of subterranean drainage. For 50 miles it flows in a north-westerly direction towards Trieste, following a shallow synclinal fold of Flysch sandstones, but as soon as it flows over the Cretaceous limestones it forms a series of deep sinuous gorges. At St. Kanzian it suddenly disappears under the surface of the plateau, passing under a massive wall of limestone over 500 feet high, above which the village is situate. From thence it passes through three immense grottos, connected by ponors (or funnel-shaped channels), and eventually emerges as the river Timava, after a subterranean course of over 18 miles. The Timava river (the source of which has been immortalized by Virgil) is $1\frac{1}{2}$ miles long, and comes to the surface as a powerful stream at the foot of a prominent limestone scarp at San Giovanni, 15 miles north of Trieste.

One of the most striking instances of underground drainage in Herzegovina is furnished by the Ombla river, which emerges from an underground channel, 3 miles north-east of Ragusa, after draining the Popovo polje, and following an underground course of over 8 miles.

In Montenegro, where subterranean drainage is a very common feature, two of the most striking instances are furnished by the Zeta and Crnojevitsa rivers. The former flows along the floor of two or more poljes, and on its uneven floor between Nitchitchi and Danilovgrad a mass of Cretaceous limestone occurs, through which the river Zeta, after draining the Nitchitchi polje, has cut an underground channel 6 miles long. It eventually reappears at the surface at Povija, close to Ostrog, and to the immediate north of Danilovgrad. The Crnojevitsa river, on the other hand, makes a sudden mysterious appearance from a huge unexplored cavern at Rijeka, and after a swampy course of 3 miles enters Lake Scutari. It is not improbable that this river may be the outlet of the drainage of the Cettinje polje or basin.

## Caverns.

Owing to its extensive system of underground drainage, the Illyrian karst is celebrated for its caverns, the most famous of which are those of Adelsberg, 50 miles east of Trieste, which are over 6 miles in length. The major portions of the large grottoes at Adelsberg

represent the former subterranean course of the Poik river, which at the present time follows a lower hidden course, which can be followed in a boat for more than a mile, mainly along major joints in the massive Cretaceous limestones. The overlying limestone at the surface is studded with innumerable circular pits, known as "ponors," which in wet seasons considerably augment the river Poik where it emerges as the river Unz at Planina. There are five main caverns at Adelsberg which of late years have attracted a great deal of attention from visitors, and for whose benefit they are now illuminated with electric light in the summer months. One of the most spacious, the "Franz-Joseph-Elizabeth" grotto, measures over 200 yards in length and breadth, and has a height of more than 100 yards. Its unusually large stalactites and stalagmites are of considerable interest.

The caverns, which are so common a feature of the Dalmatian islands, have long been famed for their extreme beauty. Many occur about sea-level, and owe their charm to the deep-blue iridescent colour of the water, doubtless the result of their being wholly in massive dolomite or limestone. Among the more important maritime grottoes, those of the island of Lissa stand pre-eminent; while the limestone grotto of Busi, a rocky islet off Lissa, has long been noted. On the mainland to the east of Ragusa-Vecchia, and south of Ragusa, is the famous grotto of Esculapius.

### Poljes.

Reference has already been made to the distinctive land forms of this region known as poljes. The polje (in Serbian: a field or cultivated area) consists of an elongated valley with a flat floor and steep sides; usually with an internal system of drainage, so that in wet seasons it is not infrequently flooded and becomes an inland sea or marsh. Poljes are usually bounded by scarp faces of Cretaceous or Triassic limestones and on their floors lie newer Tertiary sediments, which being arenaceous constitute the only fertile areas on the karstlands. While their outlines are invariably governed by the predominant Dinaric structure of the country, some appear to be the direct result of longitudinal fractures, constituting, in fact, true rift-valleys or Graben, while others are essentially the result of denudation under karst conditions, determined only in part by diastrophic processes. Several of the smaller so-called poljes of Southern Herzegovina, on the other hand, show no clear evidence of such an origin, and appear to result from the collapse of underground watercourses. To such depressions it would perhaps be better to restrict the use of the local Bosnian term "uvalas", such minor depressions being also known in Montenegro as "valas". The more important Balkan poljes are those of Livno, Glamoc, Kupres, and Duvno, in Western Bosnia; and in Herzegovina those of Nevesinje, Popovo, and Gacko. The Montenegrin poljes belong to two parallel systems following the

Dinaric (N.W.–S.E.) trend. The more easterly group includes those of Grahovo, Njegus, Cettinje, and Ljubotin. West of these occur the poljes of Nitchitchi, Danilovgrad, and Podgoritsa.

All the Bosnian poljes are considered by Katzer (10) to have originated with the Miocene orogenic movements, and to be bordered by longitudinal fractures. Cvijic (3), on the other hand, maintains that every gradation exists between the minor erosion hollows of the karst and the poljes; the remarkably rectilinear form of the latter being due to the prevailing strike of the limestones.

All the Bosnian poljes agree in possessing remarkably straight and almost precipitous walls surrounding a flat featureless depression, and are largely basins of internal drainage. The largest polje of the Western Balkans is that of Livno, which extends in a N.W.–S.E. direction for over 40 miles and is from 3 to 7 miles in width. Its walls consist mainly of Cretaceous limestones, and to the north-west include Triassic and Jurassic limestones, while it is floored with Upper Oligocene or Lower Miocene freshwater limestones and marls, with beds of lignite up to 10 feet in thickness. The drainage of the polje is towards the centre, streams flowing from the north-west, eventually disappearing in deep swallow holes, termed "ponors", while those draining in from the south-eastern end around Livno also eventually disappear in ponors below the surface. The Livno polje has two subterranean outlets, which each pass by means of east and west courses under the Dinaric range to the west into the Cetina valley and eventually enter the sea opposite the island of Brazza. Each of these underground channels following the line of the major joints in the Cretaceous limestones is upwards of 8 miles long. The more northern disappears in the ground to the immediate north of Bujani, and emerges close to the village of Hrvace, in the Cetina valley, while the more southern one enters the Sinjsko polje at the village of Otok. In wet seasons these channels are unable to take the whole of the drainage of the basin and for upwards of seven months of the year the Livansko polje forms an inland sea or marsh. The floor of the polje forms, however, the only fertile region in the district; consequently within the past few years efforts have been made to drain it by means of irrigation. The Glamoc, Kupres, and Duvno poljes are similar in almost every respect to that of Livno.

The Nevesinje polje, which is 15 miles long and has an average width of 5 miles, is in Central Herzegovina, to the east of Mostar. That of Gacko, which has an area of 30 square miles, lies to the east of Nevesinje, and close to the Montenegrin borders. The floor of the polje, consisting of lignite-bearing Miocene conglomerates, marls, and freshwater limestones, is just over 3,000 feet above sea-level, and is abruptly hemmed in by the Bjelasitsa and Lebrsnik ranges of massive limestone, which each attain over 6,000 feet above the level of the sea. In the Gacko polje the mountain streams, which formerly converted it into a marsh for the major portion of the year, have been dammed, collected in large storage reservoirs, and

employed for the irrigation of the Gacko plain during the hot and dry Herzegovinian summer, with the result that upwards of 2,000 acres of highly fertile marsh land has been brought under intensive cultivation.

The Popovo polje, on the northern edge of which is situated the ancient walled town of Trebinje, is in Southern Herzegovina. Its fertile surface covered with vineyards, orchards, and plantations of maize and tobacco, which in the wet season consists of half-river, half-lake, stands out in striking contrast to the wind-swept surfaces of the adjoining inhospitable and rugged karstlands. The polje extends in the direction of the main Dinaric N.W.–S.E. folds for a distance of over 40 miles, and the remarkable parallelism of the sides, together with its steep spurless walls, so well seen around Turkovitsi, are strongly suggestive of its tectonic origin. From the north it is drained by the river Trebinjstitsa, flowing in a south-easterly direction along its floor, while streams bearing the same name enter its southern end around Lastva and drain northwards. The overflow of the Popovo polje takes place westward, under the ridge of massive Cretaceous limestones behind Ragusa, by means of an underground channel, 8 miles in length. Where the waters eventually emerge near Rosgiatto, they constitute the river Ombla, a stream of considerable volume. The confirmation of its being the main outlet of the polje has been clearly proved by observing the sympathy of the ebb and flow of the river Ombla with that of the inland stream, the Trebinjstitsa. Where the Ombla emerges at the surface, under a precipitous limestone wall, nearly 1,500 feet high, it is a stream fully 40 yards broad, and of sufficient volume to work several small mills near its source, besides also providing a copious supply of fresh water for the town of Ragusa, whither it is carried by means of an aqueduct. From its source to the sea at Gravosa, the river Ombla follows a broad, winding, limestone canyon, 2½ miles long, the precipitous sides of which, covered with cypresses and olives, and dotted with villas, present a charming scene, standing out in vivid contrast with the barren, waterless karstlands which hem it in on either side.

In Montenegro the more easterly system of poljes already referred to, viz. Grahovo, Njegus, Cettinje, and Ljubotin, follow the Dinaric trend, and were probably produced by the same system of fractures that gave rise to the Popovo polje of Southern Herzegovina. Each of these depressions is floored with quaternary sands and clays, while they are surrounded by steep hills consisting of Triassic dolomites and limestones. The Grahovo polje, which has an area of about 6 square miles, is the largest, that of Cettinje (also known as the Cetinjsko polje), in which the chief town of Montenegro is situated, being about half that size. The more easterly group, including those of Nitchitchi, Danilovgrad, and Podgoritsa, are drained by the Zeta river. Of these, that of Nitchitchi is the largest, having a total area of about 20 square miles.

### Canali.

Closely related to the poljes, and of similar origin, are the long fjord-like arms of the sea, along the Dalmatian coast, known as "canali", which, judging by their outline and analogy, appear to constitute karst poljes drowned by the sea. The most prominent of these is the Canale della Morlacca, which can be traced from Porto Re, near Fiume, for upwards of 100 miles as a deep channel in a south-easterly direction. Its southern limits appear to be marked by the Mare di Novigrad, and the Mare di Karin near Obrovazzo. This channel, which has an average width of 3 miles, lies throughout its course close to the boundary between the Cretaceous limestones and the older (Carboniferous and Triassic) rocks, the latter forming the abrupt western scarp of the Velebit mountains, rising to heights of over 1,000 feet within a very short distance of the coast. Another striking fjord-like depression is that known as Canale dell' Arsa, which is 10 miles long and $\frac{1}{2}$ mile wide, extending north-westwards from the Quarnero into the Istrian peninsula. It has abrupt parallel sides with several well-marked rectangular bends, and on its floor on the mainland occurs Lake Arsa (or Cepić), which is known to be rapidly increasing in size, probably owing to the blocking up of its subterranean outlets. Further south, where the Dinaric strike sweeps east and west, are several canali following a similar direction. The more important are those of Lesina, Curzola, and the Canale della Narenta.

### The Cattaro and Scutari Depressions.

It is in the Cattaro and Scutari districts where the most intense earth-movements have taken place that is found by far the grandest scenery in all the Illyrian karstlands. Here the profound effect of earth-movement is clearly revealed in the remarkably abrupt features met with. The steep and imposing nature of the mountains that encircle the several bays constituting the Bocche di Cattaro, and also enclosing the plain on which Lake Scutari is situated, strongly suggest that both of these fjord-like hollows are primarily the result of extensive block-faulting, and as such they have been generally described. The Bocche di Cattaro consists of three separate basins and soundings have shown that all three of them attain a considerable depth below their outlets. In the outer bay the great southern wall of the Kumbur channel trending north-west from below Radovits is sheer and spurless, and has every appearance of a large fault-scarp running towards Castelnuovo. Similarly, between the bay of Teodo and the inner Gulf of Cattaro, is the Teodo peninsula, which rises sharply to over 2,500 feet above sea-level. Both the western and eastern walls of this massif rise with sheer sides from the floor of the gulf and along the sides of the Cattaro-Cettinje coach-road around Fort Trinita there is clear evidence of faulting in continuity with these scarps. The eastern wall of the inner bay of Cattaro has also an almost sheer face. Numerous

hanging valleys notching this limestone scarp to the north and east of the town of Cattaro significantly suggest that these movements took place in comparatively recent geological times. The remarkable straightness of the valleys, together with the truncation and facetting of the spurs, so admirably displayed on both sides of the Teodo massif, would appear to lend additional support to such a view.

In a general manner, the Scutari basin is analogous to that of Cattaro, and both its eastern and western walls are remarkably abrupt. The latter, separating it from the sea, is known as the Sutorman range, and consists of massive Cretaceous dolomites, which exhibit a remarkably unbroken rectilinear scarp-face when viewed either from Virpazar to the north or Scutari on the south. Through the southern end of this ridge the river Boyana has cut a narrow defile, which forming the only outlet of the basin results in the whole of the floor of the Scutari depression being not infrequently flooded. The eastern wall (which also forms the eastern boundary of the Nitchitchi and Podgoritsa poljes) consists of massive Cretaceous limestones and dolomites, capped in places by older Tertiary limestones. Banked against the eastern face, highly fossiliferous and marine Lower Pliocene beds have been met with at Kopliku,[1] strongly suggesting that in early Pliocene times it already formed a fjord of the sea; and that, like the Cattaro depression, its main outlines were probably determined in Miocene times. Cvijic,[2] on the other hand, holds that the maximum intensity of fracture and subsidence took place in the Quaternary period. While the remarkably abrupt nature of the features tend to support such a view, it is a very significant characteristic of all the structural depressions of the karstlands, including the poljes, that they invariably contain Upper Miocene or Pliocene freshwater beds on their floors.

### Limestone Surfaces and Outlines.

One of the most distinctive features of the Dalmatian islands and littoral, especially when viewed from the sea, is their generally smooth and rounded outlines and contours. Except where the limestone surface is quite bare, or where recently formed river-gorges cut across the plateau, the worn surface is remarkably free from crags and pinnacles. These have been described in some detail by Professor Gregory,[3] who refers to them as "pseudo-glacial" features, but points out the complete absence of any evidences of glaciation in this area. They would appear to be "down"-like surfaces, due to the weathering of the limestone, such as are so familiar on the Chalk uplands of Southern Britain and North-Eastern France.

[1] H. Vetters, "Geologie des nördlichen Albaniens": *Denksch. Math. Kl. k. Akad. Wiss.*, Vienna, vol. lxxx, 1906, p. 4.

[2] J. Cvijic, "Die dinarisch-albanische Scharung": *Sitzungsber. d. Akad. d. Wissensch.*, Vienna, vol xc, 1901, pp. 31 et seqq.

[3] J. W. Gregory, "Pseudo-Glacial features in Dalmatia": *Geogr. Journal*, London, vol. xlvii, 1915, pp. 105–17.

But while the general outline is a down-like form, where the limestone surfaces are quite devoid of any protective covering of vegetation or red earth, very slight variations in rock-texture or composition such as dolomitization, result in the production of a highly fretted surface, known as grićs or lapiés. It is on the purest limestones and where running water can operate on a great scale, such as the bare regions of Herzegovina, to the north-east of the Narenta, that the more typical grićs are to be found. More usually there are scattered patches of red earth covered with sage-bush, alternating with bare patches, where a stunted vegetation flourishes in clefts. Such regions have been described as esserts.

### Ponors and Dolinas.

The funnel-shaped hollows which are so frequently met with on the surface of the karst are termed ponors. Many of these are largely filled with red earth, formed by the decomposition of the limestone, and are then known as dolinas. The former Austrian maps of the country to the east of Trieste indicate upwards of two hundred ponors in an area of some 30 square miles, not including innumerable minor hollows and dolinas. One of the largest is known as Katchna-Jama, and is close to the village of Divatcha. It is over 1,500 feet deep ; around it are no signs of faulting or movement, and it appears to have originated along a major joint in the massive Cretaceous limestone, and to have been enlarged solely by the action of running water.

The mode of origin of the Illyrian dolinas has given rise to considerable discussion. Cvijic (2) many years ago pointed out that it is only in exceptional cases where they originate through the collapse of vaults of underground watercourses and grottoes. There is now general agreement that in the first place they are due to the simple penetration of meteoric waters localized by small fissures. An important feature is the marked abundance of dolinas in such areas as Southern Istria and the neighbourhood of Adelsberg, where there is a fairly continuous covering of red earth, and a dense growth of low vegetation, while they are comparatively infrequent on the bare limestone surfaces. In the former cases the enlargement of the clefts takes place more rapidly, presumably because of the greater erosive power of water when charged with suspended matter, and also (according to Chaix-Du-Bois (9), who has studied the Adelsberg district) probably because chemical erosion is powerfully augmented where the vegetation is more intense.

According to Grund (7), the greatest erosion probably takes place immediately above a uniform plane of saturation or water-table at the base of the karst limestones. The continued uplift since Miocene times has lowered this plane, with the result that with each successive uplift vertical erosion has ensued, while with each stationary period lateral erosion took place, resulting in the complicated system of hollows that now stud the karstlands. Martel (4).

on the other hand, who has exhaustively explored many of the Illyrian caverns, maintains that the existence of such a water-table is at variance with many facts ascertained by speleological research, and holds that the present forms are the result of true subterranean rivers flowing beneath the surface of the karst. It seems clear from his researches that much greater importance must be attached to the mechanical action of water containing solid matter in suspension, flowing along fissures and cavities in the limestone, and conversely less importance to the effects of interstitial percolation than has hitherto been attributed to it by Grund and others.

One of the most extensive and remarkable dolinas in Western Yugoslavia is that of Kocevlje (or Gottschee), 40 miles south of Ljubljana. Here on the limestone plateau occurs a funnel-shaped depression, whose superficial area is about half a square mile, and whose upper portion is filled with Upper Tertiary freshwater limestones and marls, in which are interbedded six seams of lignitic coal; the latter totalling in all a thickness of over 100 feet. Two of the principal seams, which consist of almost pure woody coal up to 40 feet in thickness, have been extensively worked, both by open-cast and subterranean mining. These Upper Tertiary lignitiferous beds dip slightly towards the centre of the dolina, and through the centre of them passes an irregular circular plug of tufaceous limestone. This has been met with in the deepest workings, which have so far been carried to a depth of 210 feet. In this remarkable instance we have preserved intact the later geological history of this area; the beds, if, indeed, ever occurring continuously there, having been completely removed from the neighbouring karstlands.

### Present-day Conditions.

In the preceding pages it has been shown that karst conditions have been developing ever since the Miocene uplift of this region; it is clear, however, that present-day climatic conditions have a powerful effect on the landscape, while other factors have contributed towards its accentuation within historic times. Judging from historical records, much of Illyria, which constituted the flourishing province of Liburnia in the Roman era, was comparatively thickly wooded with beech and conifers, and this condition would assist in the gradual accumulation of a thin veneer of "terra-rossa". Since that period the wood has been gradually removed, both by the Venetians to supply the innumerable piles on which their city is built, and also by them and the Ragusans to build their extensive fleets. This, coupled with the indiscriminate cutting of timber for every conceivable purpose, and the destruction of young shoots by the countless herds of goats reared in this region, have left much of it unprotected, so that in the hot, dry summer, the "terra-rossa" covering is carried away to produce the extensive sand-dunes seen to the north-east of Gospits, to the south of Koprivnitsa and elsewhere. In Montenegro the wood has been indiscriminately removed,

both by the Montenegrins themselves and also by the Turks, partly to prevent ambush along their former northern frontier. Rainfall and wind have completed the work of destruction by removing the loose humus, producing a region of unrivalled barrenness. Districts like the Sinjavina Planina, which were known to be well-wooded and to contain numerous settlements less than 200 years ago, are to-day dreary stony wastes.

The most powerful factor at the present day in the production of the bare surfaces is the dry and cold wind, known as the "bora", which blows with extreme severity from the high uplands to the north of the Illyrian wastes throughout the winter months. Bosnia, which is little affected by the "bora", is consequently not so bare as regions nearer the coast and the majority of its uplands are thickly covered with deciduous forests. Herzegovina, on the other hand, the barren nature of which is proverbial, suffers considerably from its effects. The necessity for a close study of the karst and its geology was recognized many years ago by the former Austrian authorities. The shortage of water in many summers is acute, for in some cases a whole group of Herzegovinian or Dalmatian villages are dependent on a single well. Springs and wells are also so infrequent on the Montenegrin karst that the few that exist have become famed in national poetry, and have been the cause of endless dispute and bloodshed in the past. By the construction of storage reservoirs, and the irrigation of the floors of many of the poljes, the shortage of water has been met in part, and what were formerly inland marshes, unhealthy in summer time, have been converted into rich agricultural districts. Afforestation has also been systematically carried out along the Dalmatian coast for the last forty years, with the result that much of the country between Ragusa and Spljet is now covered with a luxuriant growth of beech and pine.

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## The Age of the Hirnant Beds.

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THE age of the Hirnant Beds has for a long time been a matter of uncertainty, occurring as they do at the junction of the Ordovician with the Silurian. They were originally included by Sedgwick in his "Upper Bala",[1] and in the Memoir of the Geological Survey on North Wales [2] they are grouped with the Bala, and therefore in a modern classification would be relegated to the Ordovician. In 1879,[3] however, Ruddy stated that the grits representing the gritty facies of these beds in the northern part of the area were the same as those coloured Lower Llandovery on the Geological Survey map, and he then held this view of their age, though later, in 1885,[4] he placed them at the top of the "Caradoc or Bala Series". Hughes [5] also regarded the Hirnant Beds as representing the base of the Silurian, though he regarded the Ashgill Shales of Fairy Gill and elsewhere as Ordovician. Marr [6] has also always regarded the Ashgill Shales of Fairy Gill as "Upper Bala", and has included them in his Ashgillian division at the top of the Ordovician. It is perhaps significant that Salter in his Catalogue [7] includes the fossils from both sets of beds in the "Upper Bala", but divides this into two:—

(*a*) The Hirnant Limestone and Llanfyllin Beds.

(*b*) The Llandovery (Lower Llandovery of the Survey).

Thus, whilst opinion regarding the age of the Hirnant Beds has clearly been divided, there has been a general consensus that the equivalent beds in the Lake District area were of Ordovician age.

The fauna that these beds contain appears to be a very definite one, though some forms are difficult of identification, in fact, much of the difficulty has centred round the identity of the two species, *Orthis hirnantensis* M'Coy and *Strophomena siluriana* Dav.; some geologists have considered these synonymous, whilst others have regarded them as distinct fossils characteristic of different horizons.

I have recently been able to show [8] that the two fossils, whilst possessing certain undoubted resemblances, are nevertheless quite

[1] *Quart. Journ. Geol. Soc.*, vol. i, 1845, p. 6.
[2] *Mem. Geol. Surv.*, vol. iii, 1866 and 1881 (2nd edition).
[3] *Quart. Journ. Geol. Soc.*, vol. xxxv, 1879, p. 200.
[4] *Proc. Chester Soc. Nat. Hist.*, No. 3, 1885, p. 113.
[5] *Proc. Chester Soc. Nat. Hist.*, pt. iv, 1893, p. 141.
[6] *Quart. Journ. Geol. Soc.*, vol. lxix, 1913, p. 1; and *Quart. Journ. Geol. Soc.*, vol. lxxi, 1916, p. 189.
[7] *Cat. of Cambrian and Silurian Fossils*, 1873, p. 72.
[8] *Quart. Journ. Geol. Soc.*, vol. lxxviii, 1922, p. 132.

distinct, though both occur in the *same beds*. I have also given reasons for the suggestion that on the evidence available, admittedly not entirely satisfactory, the beds in question were more likely to be of Silurian than of Ordovician age. This summer I have obtained additional evidence which goes considerably further towards the solution of the problem.

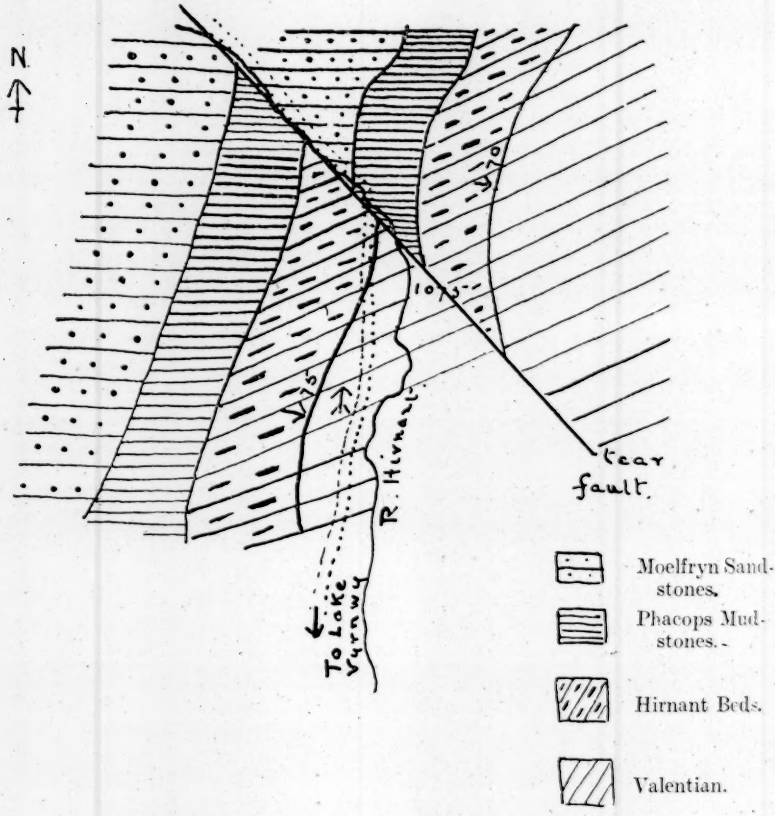


FIG. 1.—Sketch-map of Bwlch yr Hŵch. Scale 6 inches = 1 mile.

Close to Bwlch yr Hŵch (Fig. 1), in the Hirnant Valley, where these Hirnant Beds are typically developed, they consist of a series of soft blue-grey mudstones, some of which are calcareous, containing the well-known pisolitic Hirnant Limestone in large concretionary masses; these beds have yielded :—

*Orthis hirnantensis* M'Coy. C.
*Orthis sagittifera* Dav. C.
*Strophomena siluriana* Dav. C.
*Platystrophia biforata* var. *fissicostata* (Schloth.).
*Dalmanella elegantula* (Dalm.)
*Monticulipora fibrosa* (M'Coy.).

This is the characteristic " Hirnant " fauna.

The relation of these beds to those above and below is shown in the accompanying section (Fig. 2); the pale grey Moelfryn Sandstones occupy the greater part of the Pass, which owes its steep-sided character to them; at its south-east end are seen the Foel y Ddinas or Phacops Mudstones, a sandy mudstone group clearly related lithologically to the Moelfryn Beds; the development of the Hirnant Beds which succeed, ushers in an important lithological change, for these are soft dark-blue mudstones, in which slaty shale bands are intercalated with increasing frequency until the whole is a purely slate group with more and more definite banding the higher we go in the series. The higher beds have yielded graptolites characteristic of two definite horizons, those of the Upper Birkhill and Lower Gala respectively. So that so far as this section is concerned, the Hirnant beds are either referable to the highest portion of the Ordovician and the whole Valentian, extremely thin, or else they represent beds of Lower Valentian age.

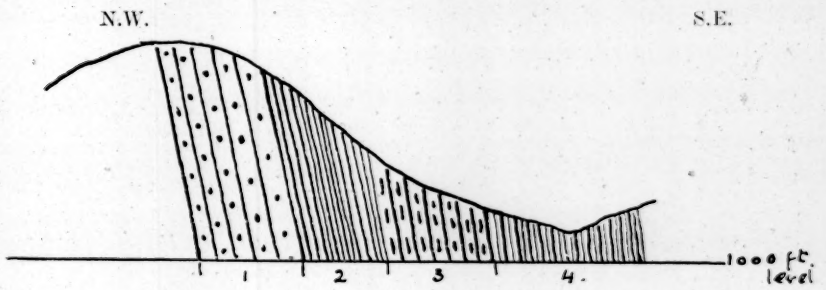


FIG. 2.—Section S.W. side of Bwlch yr Hŵch. Hor. scale 6 inches = 1 mile. 1. Moelfryn Sandstones. 2. Foel-y-Ddinas Mudstones with Phacops. 3. Hirnant Beds. 4. Valentian.

Traced northwards along their strike these beds gradually lose all their calcareous and argillaceous matter and become sandstones and then grits of fairly coarse texture, but they still contain a "Hirnant Fauna"; traced southwards, on the other hand, they seem to pass definitely into sediments of a deeper-water nature, whose age can be determined without any difficulty. Unfortunately, owing to the nature of the ground, the outcrop cannot be followed continuously, as it disappears for the most part under a wide stretch of boggy, peat-covered moor; the Moelfryn Sandstones can, however, be traced easily, as they form a more or less definite feature, and outcrops are fairly numerous, and the trend of the higher Banded Slates is also fairly obvious, the intervening softer beds being concealed. When, however, all the beds are once more seen about 2½ miles south of the original outcrop, their relationships seem perfectly clear. Here at Bwlch y groes, the Pass over from Llanuwchllyn to Dinasmawddwy, they are very well exposed, and can be traced for some distance on either side; the light grey Moelfryn Sandstones

are easily recognizable, though somewhat finer in grain and with more numerous mudstone bands. Overlying them come, as before, the Phacops Mudstones, here slightly more shaly in character, and containing one narrow, but definite, calcareous band, whilst immediately above these in the place of the Hirnant Beds come

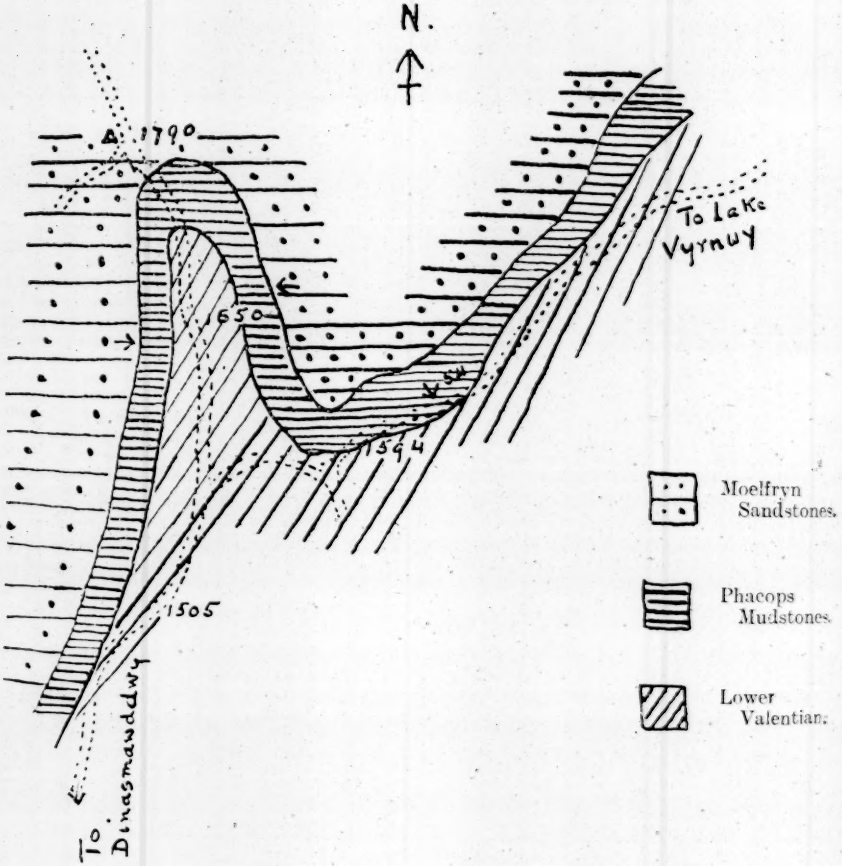


FIG. 3.—Sketch-map of Bwlch y groes. Scale 6 inches = 1 mile.

Graptolitic Shales with a well-defined Lower Birkhill fauna, comprising :—

*Monograptus atavus* Jones (small fragments).
*Dimorphograptus extenuatus* E. & W.
*Climacograptus normalis*. Lapw.
*Climacograptus rectangularis* (His.).
*Mesograptus modestus* var. *diminutus* E. & W.

This assemblage clearly indicates the *subzone of Monograptus*

*atavus*, the lowest of the three subzones into which the *Orthograptus vesiculosus* zone can now be divided. All these beds are well seen at the top of the Pass; they are then succeeded on the southern slope by definitely banded Graptolitic Shales, which are not very fossiliferous at first, but contain more graptolites to the south, in the neighbourhood of Blaen y Pennant, where all the main Birkhill horizons can be recognized; these pass up in turn into the still more conspicuously banded shales containing the Gala-Tarannon (Upper Valentian) fauna *Monograptus discus* Tqt., *M. crispus* (Barr.), and *M. marri* Perner.

There would therefore seem to be little room for doubt that the Hirnant Beds must be regarded as being of Lower Valentian age, their peculiar character in the typical locality and the comparative rarity of this fauna in general being possibly accounted for by the fact that the beds are essentially of a transitional nature between the typical shallow-water sediments of the north and the deeper-water deposits of the south.

These facts also agree well with those noted at Conway,[1] where the Conway Castle Grit, which seems to contain this Hirnant fauna, rests upon beds with *Phacops mucronatus*, and is itself overlain by Graptolite Shales, with a Lower Birkhill fauna.

If, as seems to be the case, the Ashgill Shales of the Lake District also contain this "Hirnant" fauna, it would appear as if the upper limit of the Ashgillian should be drawn beneath them, and in this connexion it is worthy of notice that the "*Dimorphograptus*" beds, referred to as constituting part of the basal series of the Silurian in the areas where the Ashgill Shales are described contained a fauna characteristic of an horizon still higher within the Valentian than that of the beds seen at Bwlch y groes.

If the zone of *Orthograptus vesiculosus* be subdivided into three, as has been done by Jones,[2] viz. :—

Zone 9. *Orthograptus vesiculosus* —
- Sub-zone, *Monog. cyphus* = "*Dimorphograptus* Zone", of Lake District.
- Sub-zone, *Monog. acinaces*.
- Sub-zone, *Monog. atavus* = Hirnant Beds.

the difference in horizon is clear. The assemblage of graptolites in the *Dimorphograptus* zone of the Lake District is that characteristic of the sub-zone of *Monog. cyphus*, so that in a shallow-water facies there must be a considerable thickness of beds below to be included in the Valentian as at present understood. If the base of the Silurian be taken as suggested above, at the base of the Hirnant Beds or their equivalents, the horizon is easily recognizable from a palæontological standpoint either by the advent of the "Hirnant"

[1] Elles, *Quart. Journ. Geol. Soc.*, vol. lxv, 1909, p. 169.

[2] Jones, "Gothlandian or Silurian (Great Britain)": *Handbuch der Regionalen Geologie*, Bd. iii, i, 1917, p. 85.

fauna, in the shallow-water facies, or by the coming in of *Monograptus* and *Dimorphograptus*, in the beds deposited in deeper water.

I gladly take this opportunity of acknowledging the assistance I have received this summer in the field from my friend and old pupil, Miss E. W. Gardner.

## An Aeolian Pleistocene Deposit at Clevedon.

By Edward Greenly, D.Sc., F.G.S.

(*Concluded from p. 376.*)

*Other Localities.*—Eight feet of loamy sand have been found in Walton Park Hotel garden, and are banked against the cliffs about 330 yards south-west of Ladye Bay. Mr. G. E. Male has lately found what he considers to be the same sands on the southern slopes of Worle Hill at Weston-super-Mare. Beyond Yatton there is some obscure stony sand in a gap of Cadbury Hill, near Cleve, and a trace of sand on the summit which cannot have been derived from waste of the limestones. No other signs of these deposits have yet been detected in Somerset, so far as I am aware, away from the Clevedon ridges, though traces of them may be looked for on the southern slopes of the Mendip and other adjacent hills.

In *Geology in the Field* (published by the Geologists' Association), however, a short summary is given of certain accumulations that are known in the Cotteswolds. At various levels on the sides of those hills there are yellow quartzose sands, more or less mixed with rock debris, and the sands, with which there are occasional bands of clay, spread out on to the lower lands. Mammoth and other vertebrates are found in these sands near Cheltenham, and freshwater shells of living species near Stroud. Some of the rock-fragments are slightly rolled, and when the formation is traced northwards erratics begin to appear. I have not seen these deposits, but they seem to resemble those of Clevedon in several particulars, though with differences that might be expected some 35 to 45 miles away to the north-east. Perhaps even the sands, loams, and rubble-drifts of southern England may yield interesting parallels.[1]

### The Age of the Deposits.

Professor Reynolds remarks that the probable presence of the Arctic fox and the Norway lemming, with the character of the voles, all point to a "very considerable antiquity"; and Mr. Martin Hinton regards the fauna as not later than the Middle Pleistocene. All the vertebrates, however, were found in the lowest of the deposits, so that the loam, sand, and upper breccia must be somewhat later. The formation shows no sign whatever of marine reassortment or marine erosion, but as it is not seen below 30 feet

[1] With regard to all the sections mentioned in this paper, I desire to point out that I have not re-visited Clevedon since my return to North Wales in April, 1920.

O.D., its relation to the 25 ft. raised-beach of Woodspring and Weston is unknown. Sands as old as the Middle Pleistocene might be expected to have undergone some subaerial erosion (such as sheets of boulder-clay invariably show here and there), but the curving surfaces of these are wonderfully smooth and free from channelling. Yet not only the general character of the fauna,[1] but the abundant angular detritus, are suggestive, if not of a sub-arctic climate, at any rate of severe winters. When the Welsh ice-sheets were gradually receding, North Somerset, though habitable, would have been extremely bleak in winter. Perhaps we may refer these accumulations to some stage of the waning of the Glacial period.

## The Origin of the Deposits.

To what agency are we to ascribe these accumulations? It must, in the first place, be one that operates upon a land-surface, for the fauna leaves no doubt that they are wholly terrestrial. Running water may be suggested by the generally stratiform arrangement at Holly Lane, and the jumble of bones inside the cave may seem, at first sight, to demand some such an agent to carry them in. But the terrestrial fauna, the exclusively local derivation and remarkable angularity of the blocks, with the absence of internal stratification in each of the bands of deposit, are not aqueous phenomena. Moreover, whence could such a river have come, and whither did it flow? Consider the physiography (Fig. 1). The Vale of Gordano is as open at East Clevedon Gap as it is at Portishead. At one end is the Channel, just outside the Severn's mouth; at the other are 150 square miles of alluvial plain. There is no possible course for such a river. Further, these beds climb up to at least 120 feet (perhaps 180 feet) O.D., so that, if we invoke this agency, we must drown the greater part of Somerset under more than 100 feet of water; water, too, which cannot be admitted to be marine! Plainly some other agency has been at work.

Now the breccias are manifestly of the nature of local talus. The fauna points, if not to sub-Arctic, at any rate to cold conditions. We may therefore look upon these breccias as ancient scree, such as is detached from crags by frost. But how could scree find its way into, and nearly fill up, the cave? A fortunate circumstance points out the way. At the door, the crag is vertical. Rubble from a surviving patch of breccia near the cliff's brow is now falling just at that spot, piling itself up, and slipping back into the cave, which it has already partly refilled, and will easily refill up to the level of the crown of the arch, thus plainly indicating for us the manner in which the same result was achieved in Pleistocene times. But special facilities existed then. In a severe climate, frost would furnish abundant scree-material which, falling over the cliff, would pile itself up in a bank, which, elsewhere sloping only outwards,

[1] Mr. Hinton urges that *Microtus nivalis* does not, *in itself*, imply any great degree of cold.

would, at the cave's door, slope inward also. Snow, gathering in drifts, would mix with it, begin to slide, and when thaw came would make the gliding of the scree-bank into the cave quite an easy matter. With the sliding of the talus, any skeletons of animals who had sheltered and died at the crag's foot would be disintegrated, and the bones jumbled about, not to speak of being trampled by their successors.

What agency, however, transported the dusty sand of alien derivation, which not only occurs in massive banks, but also functions as the matrix of the breccias ? There is one agent which could do all these things. That agency is *Wind*. Wind could bring the dust from far away, gather it in drifts, drive it into every chink of the scree, pile it along the steep scree-slopes and thence down the gentler slopes below, leaving it for the most part unstratified, though here and there with such impersistent bedding as is often to be seen in dunes. If mixed with snow, melting would bring settlement, and give us an explanation of the little local faults. Blocks of rock still falling from the crags would mingle with the sand, whose action would accentuate the tetrahedral or "dreikanter" forms. With the drifting and shifting of the sand, they would frequently be undermined, and in the course of years this process (aided by the well-known gliding tendency of snow) could move them far down the gentler slopes, thus enabling us to account for the scattered blocks which we find in the middle of the valley, and for their derivation from both the northern and the southern crags. Wind would drive the light land-shells before it, breaking most of them into tiny flakes, and allowing them to stand at all angles in the drifting sand. Wind would leave minute quartz-grains angular, while imparting to larger and heavier ones the dull and pitted surface that is characteristic of dry friction. A few yards of the crag's foot at the eastern end, recently disinterred, are curiously rounded, in a way that is quite unlike the result of water-action upon limestone. They are pitted and dimpled, with many short grooves, narrow hollows being rubbed smooth, and there is a low polish in places. The phenomena closely resembles the work of natural sand-blast. In the summers of better seasons, a scanty vegetation could grow upon the banks, and its rootlets would leave the capillary tubes of the Holly Lane loam.

Further, if we suppose the prevalent storms to have been from a northerly direction, we can account for the absence of these dusts from the high plateaux, for their feeble development upon the sea-cliffs, for their great thickness along southern slopes, and for their maximum accumulation at the foot of a crag of more than 60 feet in depth, under whose lee they would tend to gather in drifts. We can also understand why the deposits are interrupted at the lane, for that lane is carried down a gap in the ridge, the blasts driving through which would prevent accumulation.

Finally, the same hypothesis will enable us to account for the concentration of the bones along the cliff's foot, and especially within

the cave. This hardly seems to be accounted for by its having been a den of occupation. But if it, and also the cliff's foot, were a place to which both carnivores and herbivores crowded for shelter from furious northerly storms of dust and snow, all becomes intelligible. Cowed by the tempest, pursuer and pursued would scarcely (as is well-known under such circumstances) be aware of each other's presence, and all would be overwhelmed in a common destruction by the drifts. They would crowd about the cave's door, where the best shelter would be obtained. No vertebrate remains have been found in the unsheltered places. Their bones would be jumbled up as we have seen, and wind could easily whirl a little vole-jaw into the neural canal of a horse's vertebra. Man may never have visited the spot at this time, but have come there during the accumulation of the upper talus, by which time both the cave and the remains of the larger vertebrates would have been completely buried.

In short, we may look upon the breccias as frost-shattered local talus, and the alien loams and loamy sands as dusts transported by northerly storms, while the same snow-storms and the accompanying climatic conditions generally can account for the filling up of the cave and for the peculiar distribution of the vertebrate and molluscan remains.

## The Loess: A Comparison.

Let us now turn to a consideration of the Loess. That remarkable accumulation is described as a sandy loam, with occasional beds of sand; and the Clevedon drifts are loams and loamy sands. The principal differences in composition seem to be that at Clevedon there is too much sand and too little white mica for complete correspondence. But here the petrological contrasts end.[1]

The loams, in both cases, are feebly plastic, siliceous, calcareous, and ferruginous, and there is the same angularity in their minute quartz. As in the foreign deposit, the finer quartz of the sands is angular, while its larger grains are often rounded, with the characteristic dull surface of aeolian transport.[2] Loess, as the hill-sides are approached, begins to contain angular blocks of rock, and passes gradually into coarse talus with a matrix of loamy sand, to which we have a precise parallel at Clevedon. In both cases, the angular blocks are of exclusively local derivation, whereas the fine materials are alien, and of constant composition, quite independent of locality. The structural parallels are interesting. There is the same plentiful lack of stratification, the same singular vertical cleavage, the same calcareous concretions, and even the same capillary tubes with remnants of carbonaceous matter.

[1] I have not yet seen any account of the heavy minerals of the Loess.

[2] I do not remember any reference to this last feature in Richthofen's and Tietze's descriptions. But it may not have been recognized on the Continent at that time as a product of aeolian action.

Above all, the form of the accumulations, and especially the mode of distribution with reference to physiographical features, are identical; the Clevedon drifts clinging to the hills in the manner of a true "Flankenlehm" (Fig. 3). Richthofen describes the characteristic profile of loess in hilly countries as that of a rope stretched loosely across from hill to hill, and it will be seen from Fig. 4 (whose vertical and horizontal scales are equal) that this is precisely the profile of the drifts in the Vale of Gordano. There is also the same asymmetry, the Clevedon "Flankenlehm" being banked up more thickly on southern than on northern slopes; with reason, in each case, to ascribe this to the direction of the prevailing winds.

Turning to the fauna, we find that of both formations to be thoroughly terrestrial, the only exception being that at Clevedon, which is close to the sea, there are two species of sea-birds, with five fragments of marine organisms that could have been brought by them or the other large carnivorous birds. Land-shells are locally abundant in the Loess, though very sporadically, being often absent altogether; and this is precisely their mode of distribution at Clevedon. Four genera and sub-genera (*Helix*, *Hygromia*, *Succinea*, *Pupa*), and two species are common to both formations, *Helix* (*Hygromia*) *hispida* Linn.[1] and *Pupa muscorum* Linn., which are the most characteristic shells of the Loess, being found in great numbers at Clevedon. Vertebrates, locally abundant in the Loess, are locally abundant at Clevedon. More than eight mammalian genera (horse, bear, wolf, fox, Arctic fox, rabbit, voles, and lemming) and six species (with one or two birds) are common to the two. The voles, remarkably numerous in the Loess, were found in hundreds at Holly Lane, with a goodly number of bones referred to the Norway Lemming, a characteristic Loess form. The mode of occurrence of the vertebrates was the same in each case, for they are crowded together in rock-shelters, caves, and crannies.

Altogether, out of twenty-three characteristics, there may be said to be twenty correspondences, and two partial differences. There is only one complete contrast, that of the marine organisms, which is, of course, readily explicable by the proximity of the sea. The tabular presentation given will perhaps bring these out more clearly. In this table the symbols are :—

| | |
|---|---|
| Decided Development . . | — |
| Imperfect Development . . | × |
| No Development . . . | 0 |

| Characteristics. | Loess. | Clevedon. |
|---|---|---|
| Loam abundant, siliceous, feebly plastic . | — | — |
| Loamy Sand abundant . . . . . | × | — |

[1] Mr. Kennard remarks that the variety of *H. hispida* which he has from several localities in the Loess of Germany has not yet been found in Britain. It is small, and resembles the living Lake District variety of the present day. Also that *H. aspicca* and *H. virgata* have not been found in the European Loess, being recent introductions into Central Europe.

| | | |
|---|---|---|
| The Loams calcareous | — | — |
| „ „ ferruginous | — | — |
| The Deposits micaceous | — | × |
| The Fine Quartz angular | — | — |
| Angular Talus of local derivation | — | — |
| Fine Matter independent of locality | — | — |
| Lack of Stratification | — | — |
| Vertical Cleavage | — | — |
| Calcareous Concretions | — | — |
| Capillary Tubes | — | — |
| Distribution dependent on physiography | — | — |
| Outline as of Loose Rope, yet asymmetrical | — | — |
| Land-shells locally abundant | — | — |
| „ 4 genera in common | — | — |
| „ 2 species „ | — | — |
| Vertebrates locally abundant | — | — |
| „ concentrated about shelters | — | — |
| „ 8 genera in common | — | — |
| „ 6 species „ | — | — |
| Voles very abundant | — | — |
| Sea-birds and marine debris | 0 | — |

There seems now to be general agreement that the Loess is a product of aeolian action in a cold climate; and the Clevedon drifts, there can be little doubt, were accumulated under similar conditions. The Loess-lands lie along the southern margin of the region of maximum glaciation. The Clevedon drifts are 12 miles from Cardiff, where we find the maximum southern extension of the land-ice of Wales.

I do not suggest any correlation, especially as Loess is well known to be of more than one age, and to be overlain, locally, by certain glacial accumulations. All that the Clevedon deposits appear to tell us at present is that, at some time during the latter part of the Pleistocene period, Loess *conditions* extended from the Continent into south-western Britain.

### The Contemporary Levels.

The drifts run down to the edge of the great Somerset alluvia (Fig. 2) with a slope of 7 degrees, and without any sign of thinning-out, so that, as they are certainly by far the older, they must pass under those alluvia, and must descend considerably below sea-level.[1] Thus, as they are exclusively terrestrial, the land must, at the time of their formation, have stood considerably higher than it does to-day. Now, the submarine contours show that, with an elevation of 50 feet, open sea would not approach to within 8 miles; and that, instead of the 12 mile sea-channel of to-day between Clevedon and South Wales, we should have a mere one mile river-channel. That conditions of this kind prevailed at that time finds some confirmation in the nature of the bird-fauna, for, with the sea as near as it is now, we should expect more than two sea-birds out of twenty-four. On

[1] Unless they were washed away by the sea during the period of the Raised Beach.

the other hand, the same fauna suggests a limit; for although it is true that gulls fly many miles inland in winter, they would hardly carry fish-vertebræ with them all that distance. The old level may, accordingly, be estimated as exceeding the present level by a good deal more than 20 feet, probably by nearly 50 feet; but not probably by much more than that.

### The Sources of the Alien Sands.

This question is closely bound up with that of level. The Coal Measures (Pennant) of Conygar have already (p. 363) been excluded. Moreover, Mr. A. Heard has lately published (Geol. Mag., February, 1922) a study of the petrology of the Pennant Series. His list of its minerals, in approximate order of abundance, is as follows: quartz,* muscovite,* coaly carbon, chlorite, zircon,* pyrrhotite, siderite, sphærosiderite, pyrite, rutile,* tourmaline,* cordierite, corundum, biotite,* felspar,* glauconite, fluorite. Comparing this with the list given on page 369, we find that, out of a total of some thirty minerals, only seven (which are marked with an asterisk) are common to the two formations. Moreover, muscovite, large and abundant in the Pennant, is rare and small in these Pleistocene sands; biotite, rare in the Pennant, is not rare in the Pleistocene; felspars, indeterminable in the Pennant, are determinable in the Pleistocene; while certain cherts are of different characters in the two cases. Zircon, rutile, and tourmaline are now known to occur in sandstones of many different ages. In fact, not a single mineral of diagnostic significance is a common constituent of the two formations, and it is evident that the Pennant sandstones cannot have been the source of these Pleistocene sands. The narrow outcrop of Old Red Sandstone is manifestly an inadequate source, especially for the loams; while, on the other hand, it would have provided much more white mica; besides which, at only a quarter of a mile away, grains therefrom derived would hardly have lost their characteristic hæmatite pellicle.

But there is a far more probable source. While the Welsh ice-sheet shrank back into the recesses of the mountains, we may be sure that its melting waters distributed wide fluvio-glacial accumulations. Most of these must have been levelled off and redeposited by the sea since it was readmitted to the Channel by the subsidence which let down the Forest-bed.[1] During the retreat of the ice, however, with the land standing at the level suggested, the newly re-born Severn must have meandered along a 12 mile wide plain of reassorted boulder-clay, fluvio-glacial gravel, sand, and mud. From such a surface, under conditions of dry cold, storms could easily sweep up vast quantities of dust and sand.

[1] Very likely the vast banks of mud and sand which embrown the waters of the Channel for some 30 miles are part of the wreckage of them, incessantly redistributed by the scour of the tides. For the Severn, Wye, and Avon are not muddy rivers above tide-levels.

Now we have seen that the distribution of the sands decidedly indicates that the winds were from northerly directions. But, further, the whole assemblage of heavy minerals is (except for the absence of augite) that which is persistently found in the Glacial sands of South Wales.[1] The two most characteristic minerals of these deposits, andalusite and idiomorphic rose garnet, are present at Clevedon.[2]

The evidence, accordingly, leaves little doubt that for the source of the alien sands we must look to the fluvio-glacial deposits of the Channel hollow, swept up in great clouds by northern winds, to be dropped by them under the lee of the nearest hills of Northern Somerset.

## Recapitulation.

The Pleistocene deposits of Clevedon consist of sandy breccias and loamy sands, banked up mainly under southern crags. From their faunal and physical relations they may be assigned to a relatively late portion of Pleistocene times, probably that of the retreat of the ice-sheet from South Wales. The land appears to have stood some 25 to 50 feet above its present level, so that the inner reaches of the Bristol Channel were laid bare. All the characters of the deposits indicate that they are essentially products of aeolian action, supplemented locally by the work of frost. Their distribution and their contents show that the winds were from northerly directions, and suggest that the sands were derived from the fluvio-glacial accumulations of South Wales and the Channel hollow. Their characters correspond in a remarkable manner with those of the Eur-Asian Loess, indicating a similar mode of origin; though explicit correlation is not made in this paper. In any case, however, the Clevedon drifts tell us of steppe conditions, of a dry cold climate, with a steppe fauna living on the land and of severe winters, with violent northerly storms of dust and snow.

## Literature.

S. H. Reynolds, "A Bone Cave at Walton, near Clevedon": *Proc. Bristol Nat. Soc.*, 1907, pp. 184–7.

H. N. Davies, "Supplementary Notes on the Clevedon Bone-Cave and Gravels": *Proc. Bristol Nat. Soc.*, 1907, pp. 188–9.

Martin A. C. Hinton, "Note on the Occurrence of the Alpine Vole (*Microtus nivalis*) in the Clevedon Cave-deposit": *Proc. Bristol Nat. Soc.*, 1907, pp. 190–1.

Martin A. C. Hinton, "On the existence of the Alpine Vole (*Microtus nivalis* Martins) in Britain during Pleistocene Times": *Proc. Geol. Assoc.*, 1907, pp. 39–58.

S. H. Reynolds, *A Geological Excursion Handbook to the Bristol District*, 1912, pp. 84–5.

[1] See note by Dr. H. H. Thomas in "Geology of Anglesey": *Mem. Geol. Surv.*, pp. 757–8.

[2] See H. H. Thomas on "Detrital Andalusite"; *Min. Mag.*, 1909, p. 241; and remarks by the same author in the discussion on the present paper at the Geological Society on 8th December, 1920.

## The Cretaceous and Tertiary Question in Jamaica.

By C. T. Trechmann, D.Sc., F.G.S.

THE geology of Jamaica compared with that of some areas of the earth's crust is neither very involved nor very difficult of interpretation. Considering the length of time that has elapsed since it was first studied and the easy accessibility of many parts of the island, it should be fairly well known and should form a key for the interpretation of the structure of the larger and less well-known islands of Haiti and Cuba, and also of Porto Rico and the smaller islands forming the group of the Greater Antilles.

Unfortunately, confusion has arisen on more than one occasion concerning the correct attribution of one or other of the sedimentary formations of the island. I desire briefly in the present paper to call attention to some of the errors that have arisen and, as I hope, to correct what I consider to be the latest and one of the most serious of these errors, namely that referring to the reputed commingling of Cretaceous and Tertiary faunas in certain of the beds.

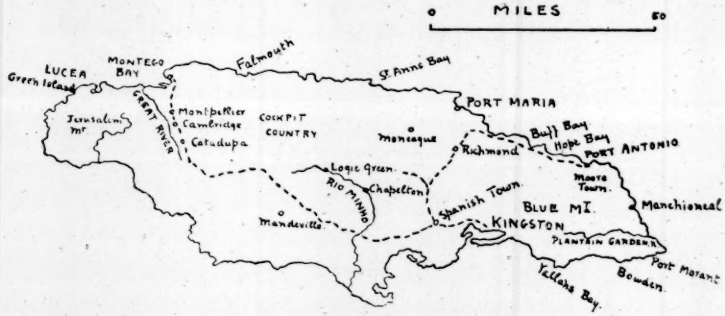


FIG. 1.—Locality Sketch-map of Jamaica.

Roughly speaking, the island of Jamaica may be said to be made up of three great constructive units; beginning with the lowest, these are :—

1. The Blue Mountain series, consisting of more or less highly folded and locally more or less metamorphosed and intruded series of fragmental and calcareous sedimentary deposits of Cretaceous and early Tertiary age.

2. The covering mass of Tertiary limestones, comprising the Yellow Limestone overlain by and generally merging up into the great White or Cockpit[1] Limestone.

3. The locally developed marginal deposits, comprising the gravel beds and white foraminiferal marls, and the beds containing the well-known Bowden fossils, together with various Post-Pliocene accumulations.

[1] Cockpit Country is the name given to an area in the north-western central part of Jamaica, but sinks of more or less cockpit-like shape are developed wherever the White Limestone forms plateaux or elevated tracts.

## SYNOPSIS OF THE NOMENCLATURE OF JAMAICAN GEOLOGY.

| De la Beche, 1827. | Sawkins and Etheridge, 1865. | | R. T. Hill, 1897. | | C. T. Trechmann, 1922. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | *Suggested Nomenclature.* | | | *Thickness.* | *Description.* |
| *i.* Coral Islands. | Alluvium (300 ft.) | Post-Tertiary. | Bogue Island | Recent and Late Pleistocene. | MARGINAL BEDS. | Post Pliocene | Coastal raised reefs | 50–300 ft. | Coral reefs often enclosing fallen masses of White Limestone or other rocks. |
| *h.* Diluvium and Alluvium. | Coast Limestone (50 ft.) | | Montego | | | | River gravels | | |
| *g.* Extinct Volcano (near Hope Bay). | Gravel Beds | | Falmouth | | | | Flood plain gravels | | |
| *f.* White Limestone Formation. | White Marl (250 ft.) | | Coast Soboruco | | | Pliocene or Miocene | Marls and Limestones | ? | White or buff coloured marls with flint, often foraminiferal. |
| *e.* Porphyritic Conglomerate and Trap. | | | Barbican | | | | Bowden Beds | 50 ft. | Gravels and shell beds at Bowden and Port Morant on the south-east coast. |
| *d.* Coal Measures. | White Limestone (2,000 ft.) | Post-Pliocene. | Hopewell | | (Unconformity) | | | | |
| *c.* Red Sandstones and Conglomerates. | | | Manchioneal | Pliocene. | COVERING BEDS. | ? Oligocene | White Limestone | Over 2,000 ft. | Hard massive "Cockpit" Limestone. |
| *b.* Trap Rocks. | Yellow Limestone (500 ft.) | Miocene. | Kingston | | | | ,, Moneague Beds | | Foraminiferal chalky bedded limestones and flint bands. Locally missing. |
| *a.* Submedial or Transition Rocks. | | | May Pen | Miocene or Late Oligocene. | | | ,, Montpellier Beds | | |
| | | | Bowden (Break) | | | Eocene | Yellow Limestone | 400 ft. | Massive yellow limestones, yellow marly limestones, shale and lignite bands. |
| | | | | | | | (Local unconformity) | | Fossils: *Carolia* in higher part, *Velates* in lower. |
| | Trappean Series (1,500 ft.) | Eocene. | Cobre | "Oceanic", Early Eocene to Early Oligocene. | BLUE MOUNTAIN SERIES. | | Carbonaceous Shale or Richmond Beds | Over 1,000 ft. | Flysch-like shales and Brockram-like conglomerates, with derived Cretaceous and fresh or slightly rolled contemporaneous Eocene fossils. Locally missing. |
| | Carbonaceous Shale (1,000 ft.) | | Moneague | | | | (Local unconformity) | | |
| | | | Montpelier | | | Cretaceous | Shales | ? 5,000 ft. | Fossiliferous limestone reefs, with Rudists and other fossils intercalated among shales and conglomerates. Red shales, with *Trigonia*, *Roudairia*, *Baculites*, *Hamites*, etc. |
| | Cretaceous Limestone (500 ft.) | | Chapelton | | | | Alectryonaria Limestones | | |
| | Marble | | Catadupa | | | | "Caprinula" Limestones | | |
| | Serpentine | | Cambridge | | | | Shales and Conglomerates "Trappean" Series | | |
| | Conglomerate | Secondary. | Richmond | Late Cretaceous. | | | Barrettia Limestone | | |
| | Metamorphosed Series (2,000 ft.) | | Minho | | | | Shales and Conglomerates | | |
| | Porphyry | | Ballard | | | | Marble | | Metamorphosed or semi-metamorphosed equivalents of the Blue Mountain Series. |
| | | | Logie Green | | | | Serpentinous Limestone | | |
| | Granite and Syenite | | Jerusalem | | | | Metamorphosed Series | | |
| | | | Frankenfield | | | | | | |
| | | | Yallahs | | | | | | |

*To face p. 173*]

The accompanying table is intended to show at a glance the names that have been given to the different formations in Jamaica since the time of De la Beche in 1827, together with, in the last column, the terminology that I suggest might be most conveniently applied to them.

The first column of De la Beche [1] was drawn up before any of the Cretaceous *Rudistæ* were discovered in Jamaica. The map accompanying the report comprises only the eastern portion of the island, including the Blue Mountain district. His Coal Measures refer apparently to an exposure of Carbonaceous Shales (Richmond beds) to the south of Port Antonio. His Trap Rocks are associated with those mentioned just below, namely, the Submedial or Transition, which is the term he uses to designate the Blue Mountain series. Sawkins's term, Trappean, appears to have been borrowed from De la Beche's earlier designation.

Sawkins's column is the one generally employed by English geologists, though it must be remembered that his term Yellow Limestone includes also the Bowden beds, which, as will presently be mentioned, are later than the White Limestone.

Hill's column is the one in general use in American literature, and he has employed the custom of giving more or less non-committal place-names to the various beds, a procedure which seems hardly necessary in a locality such as Jamaica, whose formations had been so well worked out by Sawkins more than thirty years previously.

His terms Cambridge and Catadupa formations, founded, as I shall presently show, on a mixed collection of Cretaceous and Eocene fossils, must be abandoned. The term Chapelton may be retained if it be used to designate the Yellow Limestone of Eocene age, since this bed only forms the hill on which the village of Chapelton is built.

The Cretaceous portion of his Cambridge and Catadupa beds is equivalent in age with parts of his Jerusalem, Logie Green, Ballard, and Minho beds. Curiously, however, the rock that occurs actually at Cambridge and Catadupa railway stations is the Yellow Limestone, while the succession of the Rudist and Yellow Limestones is seen along the line between these two points.

The statement of the mingling of faunas in the Richmond, Cambridge, and Catadupa beds has crept into general literature, though the occurrence of *Rudistæ* and Eocene fossils together is reasonably questioned by some authors.[2]

## Position of the Bowden Beds.

An error arose during the time of J. G. Sawkins, G. P. Wall, and the other geologists who surveyed the island between the years 1861 and 1865. This had to do with the position of some of the late

[1] "Remarks on the Geology of Jamaica": *Trans. Geol. Soc. London*, 1827, vol. ii, No. 36.

[2] E. Haug, *Traité de Géologie. II. Periodes Géologiques*, p. 1525.

Tertiary deposits, including those which contain the well-known and familiar fossiliferous bed at Bowden, in the south-east corner of the island. Anyone who examines a collection of these fossils is struck by their excellent state of preservation, and by the comparatively recent appearance of the fauna. Nevertheless, Sawkins placed the series below the White Limestone, and referred to them as the Yellow Limestone or Bowden beds. In the appendix [1] this series of fossils is referred to by R. Etheridge, who regards them as belonging to the Miocene or Middle Tertiary. On another page of the report [2] a list of the Bowden mollusca, mixed with such Eocene forms as *Cerithium giganteum*, and recent living shells, such as *Lucina pennsylvanica* and *Bulla striata*, is given under the heading of "Miocene Fossils".

It is almost certain that had it not been for the unfortunate death in 1862 of Lucas Barrett, the palæontologist of the Jamaica Survey, who was accidentally drowned in a diving bell, both the Bowden beds, the White Marls and the Yellow Limestone, would have been ultimately referred to their proper positions.

Sawkins was uncertain from the field evidence whether the position of the White Marls in the parish of St. Elizabeth, in the south-west of Jamaica, was above or below the White Limestone, but he concluded that it was more probable that they lay above. The old fossil and rock collection made by Sawkins and his fellow surveyors is still preserved in glass wall-cases in the Jamaica Institute in Kingston, but the specimens are very dusty and a good deal mixed up. Apparently the great earthquake in 1907 did not improve matters in this respect, though in the collection the Bowden fossils are still labelled under the heading of Yellow Limestone.

The position of the Bowden beds is discussed at full length by R. T. Hill,[3] who places them and other deposits in what is without doubt their rightful position among the marginal formations later than the great White Limestone.

### The Cretaceous and Tertiary Question.

A more serious and less excusable error has, in my opinion, been perpetuated by Hill in his assertion that Cretaceous and Tertiary fossils occur associated together in certain formations in Jamaica. To these he has applied the names Richmond, Cambridge, and Catadupa formations. Hill refers to this matter repeatedly in his book, and reiterates his positive conclusion that this mingling of the faunas actually exists.

Hill, after referring to the Jamaican Cretaceous, says: [4] "Several Rudistes and two species of corals from these supposedly Cretaceous

[1] Reports on the Geology of Jamaica: J. G. Sawkins, F.G.S., and others. Appendix by R. Etheridge, F.G.S., etc., 1869, p. 307.

[2] Ibid., p. 152.

[3] "The Geology and Physical Geography of Jamaica": *Bulletin of the Museum of Comparative Zoology, Harvard*, vol. xxxiv, 1899, p. 82.

[4] Ibid., p. 123.

formations continue upward into the beds which are here placed in the Eocene, indicating a graduation of the faunas of these two epochs." And, further on, "In view of the facts presented, the writer finds it utterly impossible to accept the 'rolled' hypothesis, and he can see no way of avoiding the positive conclusion that the Rudistean forms in the Cambridge beds represent a survival of Cretaceous types into the Lower Eocene"; and referring to the fossils, he remarks: "As a fauna nothing exactly analogous to it is known elsewhere."

These observations lead Hill to the conclusion that "the discovery of the Cambridge formation gives a certainty to the existence of an Eocene system in Jamaica, aggregating at least 1,500 feet in thickness"; and, further, that "the palæontologic peculiarities of the Richmond and Cambridge formations, analogous to those of the preceding Cretaceous beds, are such as can only be accounted for by geographic environment, and point to early insularity of the island through Eocene time."

Referring to the Richmond beds, Hill says: "The presence of supposedly Cretaceous Rudistean genera would ordinarily invalidate the data upon which the Eocene age of the Richmond beds hitherto depended for establishment, were it not for our positive evidence to be presented that these forms are found in situ in overlying beds, associated with undoubted Eocene fossils."

The conclusions that Hill arrived at led him to publish a map, compiled from the map of Sawkins and Brown with additional data, which contains several alterations, and in which great prominence is given to the "Cambridge" formation. With all due respect to Hill and the work he accomplished in Jamaica, I cannot regard this map as at all an improvement on the old English survey map of Sawkins.

The matter is thus one of far-reaching importance in connexion with Antillean geology, and so, perhaps, I may be excused if I give the results of my examination of the sections in question.

As regards the Richmond beds of Hill, which correspond with the beds mapped by Sawkins as Carbonaceous shale or Black shale, the examination of several sections of these beds near Port Antonio, at and near Port Maria, and elsewhere in Jamaica, led me to conclude that the pieces of Cretaceous limestone and the rolled *Rudistæ* that occur among the conglomerates in these beds are all derived from the denudation of older formations. They are exactly analogous to the pieces of Carboniferous limestone in the Permian Brockrams of England, and, in fact, some of the Cretaceous limestones of Jamaica had already been semi-marmorized before they and several varieties of gneisses and other rocks not now seen in situ in Jamaica were incorporated in the Richmond beds. The Eocene fossils that occur among the Richmond conglomerates at Port Maria and elsewhere are all either fresh or only slightly rolled and broken, and were clearly living at the time the beds were

deposited. They include several forms of *Cerithium* and *Natica*, among others, whose palæontological horizon I hope to fix in due time. There appeared absolutely no evidence that *Rudistæ* had lived during the deposition of the Richmond beds, and all of them were in the form of rolled and fossilized limestone pebbles.

Turning now to Hill's Cambridge and Catadupa formations, the critical section is that exposed along the railway cutting of the Kingston to Montego Bay railroad between Cambridge and Catadupa stations. Other Cretaceous sections in Jamaica, such as, for instance, that at Jerusalem Mountain, in the extreme west, Logie Green and the Rio Minho, in the centre of the island, or Mooretown and Plantain Garden River, in the extreme east, do not suffer the interesting imputation of harbouring a Cretaceo-Eocene fauna.

Hill publishes [1] illustrations of drawings of a discontinuous series of sections exposed in the railway cutting to the north and south of Catadupa station under the heading of "Exposure of Cambridge formation near Catadupa and Cambridge". The drawings apparently represent only those sections that are actually cut through by the railway line, and seem to ignore the beds which are exposed in numerous stream and road cuttings, both above and below the railway line. Hill indicates no faults in his section, which extends over more than two miles, and I find the sequence of beds difficult to make out in his sketches, except that the Cockpit or White Limestone overlies the "Cambridge" beds at one place unconformably. Hill's section stops about 4 miles south of Cambridge, but another section, labelled "Cambridge Station", shows two very regular anticlines and an intervening syncline.

I made several traverses, on some days in company of Dr. C. A. Matley, of the line between Catadupa and Cambridge, and also for some 3 or 4 miles south of Catadupa and north of Cambridge, both on foot and by means of a trolley which was kindly provided by the Director of the Jamaica railways. Several of the numerous stream and road sections below and around Catadupa were also investigated. Evidence of faulting and other dislocations is very strong in this district, especially in the neighbourhood of Catadupa. Faults in more than one instance bring the Yellow Limestone with its characteristic Eocene fauna into almost immediate contact with the Rudist Limestone (Fig. 2), and also in at least one case they bring red shales apparently of Eocene age underlying the Yellow Limestone into contact with Cretaceous shales of a similar colour and appearance which occur below the Rudist Limestones.

The fossils, unless collected with considerable care along this stretch of line, would tend to become mixed together, especially as in this district the Rudist Limestone often assumes a yellow colour, very like that of the true Yellow Limestone. This seems to me to be what has happened with the collections that Hill made. He says

[1] Loc. cit., p. 59.

that he made two traverses of the line for the purpose of collecting the fossils on which his conclusions were based, and his lists of the fossils [1] from near Catadupa and Cambridge, based on the determinations of T. W. Stanton, certainly indicate a mixture of forms of the Yellow and Rudist Limestones.

I feel sure that only a prolonged and detailed mapping by some geologist residing on the spot would clear up the tectonic structure of this district of Jamaica.

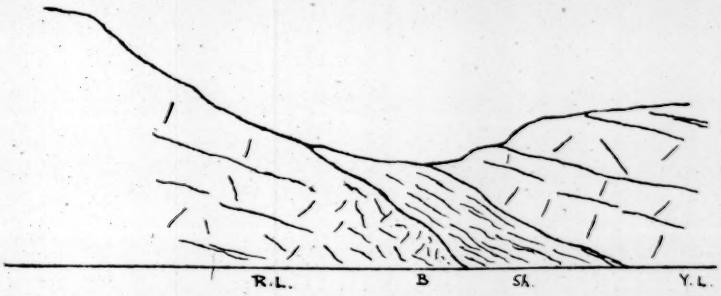


FIG. 2.—Faulted junction of Rudist and Yellow Limestone with a crushed shale intervening; on side of a stream under the railway about a mile south of Catadupa station. R.L. Rudist Limestone full of fossils, much brecciated at B. Sh. Slickensided Shale. Y.L. Yellow Limestone with casts of gigantic *Cerithia* near the top. Height of section about 20 feet.

For a distance of about 3 miles south of Cambridge station, where the actual railway cuttings are deeper and more continuous than they are to the south of Catadupa, I made a sketch of the section of the rocks exposed along the line for about a mile and a half, which show very clearly the relation one to another of the different beds (Fig. 3). These include the shaly Yellow Limestones full of the *Anomia*-like bivalve *Carolia*; the Yellow Limestone, with large specimens of *Cerithium* and *Lucina*; red shales with badly preserved fossils; Rudist Limestones, with "*Caprinula*" *gigantea* and many other forms; and shales with *Trigonia*, *Roudairia*, and other Cretaceous fossils that underlie them and form the higher part of the so-called Trappean Series of Sawkins. Overlying one or other of these beds one finds masses of the great White or Cockpit Limestone, of supposed Oligocene age.

In this section of one and a half to two miles the beds are not seriously affected by faulting, and the Yellow Limestone follows the Cretaceous Limestone with approximately the same dip and with only a few feet of red shales with indeterminable fossils separating them. This gives an appearance of the conformity of the Yellow and Rudist Limestones in this area, which is liable to lead to a false inference, since in other areas a great thickness of Carbonaceous shale

[1] Loc. cit., p. 129.

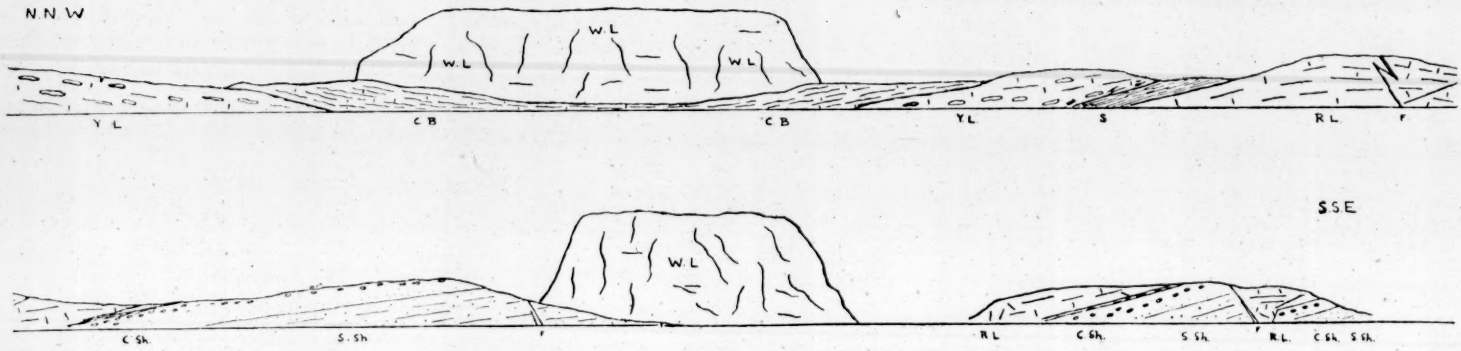


FIG. 3.—Section of Cretaceous and Tertiary beds exposed along the railway line between 1 and 2½ miles south of Cambridge railway station, Jamaica. Length of section about 1½ miles. Height of White Limestone cliffs about 50 feet. F.F. Faults. W.L. White or Cockpit Limestone (Oligocene?). C.B. Marly Yellow Limestone with *Carolia* (Eocene). Y.L. Yellow Limestone with gigantic *Cerithium* and *Velates* (Eocene). S. Shale with indeterminable fossils between the Cretaceous and Eocene beds. R.L. Rudist Limestones with "*Caprinula*" *gigantea* and numerous other fossils (Cretaceous). C.Sh. Calcareous shales, with near the top a nodular bed containing *Trigonia*, *Roudairia*, *Pholadomya*, *Janira*, etc. (Cretaceous). S.Sh. Sandy shales with *Pecten*, etc. (Cretaceous).

or Richmond beds[1] or beds mapped as Trappean intervenes between the Yellow and the Rudist Limestones, and which are absent from this section.

The White or Cockpit Limestone rests in one place along the line on rotten yellow Carolia marls, and in another place, about a mile further to the south, on weathered Cretaceous shales. I was convinced that these masses of White Limestone are partly or in some cases completely detached from the main escarpment which surrounds the outcrop of the older and softer beds in an amphitheatre-like manner, and have to a greater or less extent travelled by slipping down the slope of the valley of the Great River. The older beds in this section are much rotted and decomposed where they are seen immediately under the White Limestone. The position of the White Limestone also in this section is anomalous, since in some other undisturbed sections in Jamaica the Yellow Limestone seems to grade up with perfect conformity into the White Limestone.

### The Nature of the White Limestones.

As regards the great White or Cockpit Limestone of Jamaica, the Montpellier, Moneague, and Cobre formation of Hill, which attains a thickness of over 2,000 feet, and covers about three-quarters of the island, it does not appear to me to be advisable to apply the term oceanic to this formation. Its character does not seem to be of nearly such an oceanic nature as, for instance, does that of the English Chalk. Massive compound corals, together with pisolite-like bodies, casts of *Cerithium*, *Cypraea* and other molluscs, are common in it, forms which are by no means of oceanic but rather of shallow-water character. Unfortunately, fossils are very poorly preserved and are nearly all merely casts. It may be remarked that the supposed Oligocene age of this formation is not as yet founded on any very definite palæontological evidence. There seems to me to be absolutely no evidence to connect it in any way with the oceanic marls of Barbados. Parts of it may be of late Eocene, Oligocene, or early Miocene age. The deepest-water portion of it seems to be that which lies at the base, namely, the foraminiferal flinty chalks called the Montpellier beds, which are locally developed but very well seen near Montpellier, but in these beds also casts of bivalves and other mollusca are abundant in places. American geologists seem generally agreed in correlating the Montpellier Limestone with the Vicksburg beds.

I am strongly inclined to think that the White Limestone originally covered the whole area of what is now Jamaica, as there is no trace

[1] Dr. Matley suggested to me, what I had once or twice vaguely suspected, his opinion that the Richmond beds may possibly replace the Yellow Limestone in some parts, though in some areas, such as Glasgow in the extreme north-west, both the Richmond beds and the Yellow Limestone occur. It is to be hoped that further research both in the field and also on the fossils may assist in determining this question.

of any debris of the Blue Mountain series in it, and consequently there is no reason to suppose that any portion of the present Jamaica protruded as a land surface during its formation.

## Observations on Sawkins's Map.

Some caution is necessary in reading Sawkins's map. The original manuscript map, on a large scale, is still preserved in sections in the Jamaica Institute at Kingston, but the colours are largely faded, and the map is much eaten by white ants. The map in the survey memoir, however, seems to be a faithful reproduction of it.

The grey colour of the Carbonaceous Shale (Richmond beds) is almost exactly similar to that of the White Marls lying above the White Limestone.

Some areas of Cretaceous Limestone mentioned in the text are not indicated on the map, notably one in the far west of the island between Grange and Bosleys. Some limestones mapped as Cretaceous belong to the Carbonaceous Shale series. The Barrettia Limestone at Haughton Hall, near Green Island, in the north-west, is not indicated, but then it appears to have been unknown to the surveyors in 1862.

In the centre of the island, in the Rio Minho watershed, the beds below the Cretaceous Limestone are indicated as "metamorphosed series". They are not in reality metamorphosed, as some parts of the same formation in the Blue Mountains are. Dr. D. Woolacott traversed this area two years ago and agrees with me on this point. In the far south-west and west there are considerable areas coloured green to indicate the Yellow Limestone. The beds, apparently Hill's Manchioneal formation, are certainly limestones of a very yellow colour, and owing to the confusion of the position of the Bowden beds they are correlated by Sawkins with the true Yellow Limestone of the centre and east of the island, whereas most of them seem to belong to the series lying above the White Limestone associated with the Bowden beds. There are other instances one might mention, but the map, everyone will agree, is a marvel of industry and elucidation when one has regard to the physical difficulty and discomfort and the period at which it was made.

## Palæontological Notes.

The fossils collected along the section between Cambridge and Catadupa, illustrated by Fig. 3, are not yet worked out, and so I cannot at present indicate more than a few of the genera that are present among some hundreds of species gathered from this and numerous other localities in Jamaica.

The Calcareous shales below the Rudist Limestones in the section illustrated contain *Trigonia*, *Roudairia*, *Janira*, *Pholadomya*, and echinoderms, and corals of Cretaceous aspect.

These shales agree with part of the beds mapped by Sawkins as Trappean, and a similar looking and apparently similarly situated

bed at Providence, near Port Antonio, containing a similar series of lamellibranchs, yields also *Hamites* and *Baculites*. The Rudist Limestones are characterized by "*Caprinula*" *gigantea* Whitfield. This is the "Hippurite" which Sawkins mentions as occurring 7 feet long. At Jerusalem Mountain I collected one 5 feet long, but the generic affinities of this and several other Jamaican *Rudistæ* await a critical investigation. Among other *Rudistæ* at this locality are *Radiolites adhaerens* Whitfield, *Radiolites macroplicatus* Whitfield, *Radiolites cancellatus* Whitfield, *Caprina jamaicensis* Whitfield, and others. Among the gasteropods are species of *Actaeonella* and *Pterocera*. There are also numerous corals and some echinoderms. These limestones close the Cretaceous sequence in this locality.

The Richmond beds are not present in this section, but at Port Maria the rather scanty and fragmentary Tertiary fossils that occur in the conglomerates of the Richmond beds yield several species of *Cerithium* and *Ampullina* and fragments of *Carolia* and other lamellibranchs. I saw no trace, however, of *Velates*, nor of the gigantic *Cerithia* of the Yellow Limestone, so the Richmond may be older than the Yellow Limestone fauna. The Yellow Limestone everywhere I examined it in the central and western portions of Jamaica contains a definite and very rich and in some parts well-preserved Eocene fauna. The mollusca are sufficient to show this, apart from the evidence of any foraminifera. They include *Velates Schmideliana* Chemnitz in some variety and in all sizes up to that of a man's fist, *Gisortia*, *Campanile*, *Clavella*, *Seraphs*, and numerous forms of *Ampullina* among the gasteropoda, and *Carolia*, large *Lucinae*, and other forms among the lamellibranchs. The fauna strongly recalls that of the lower and middle Eocene of various localities in Europe, North Africa, and Asia.

Very few, if any, species of the Yellow Limestone mollusca seem to pass up into the White Limestone, although the stratigraphical passage is a gradual one. When one collects Cretaceous and Eocene fossils in Jamaica one is collecting European forms, and the general resemblance of the Jamaican fossil fauna to that of the Old World Tethys fauna persists in the Cretaceous and Eocene up to the top of the Yellow Limestone. Above that, that is to say, from the base of the Montpellier formation upwards the fauna and conditions of deposition seem to conform to the American type.